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TROPICAL CYCLONES OF THE PACIFIC

BY

STEPHEN SARGENT VISHER

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Tropical Cyclones of the Pacific

By

Stephen Sargent Visher

INTRODUCTION

The typhoons of the "Far East" have indeed received careful study, especially by Algué (1)[1] and by Froc (65), but little has been published concerning the storms of other parts of the Pacific. Furthermore, an understanding of tropical cyclones is an essential factor in the interpretation of the distribution of life in the Pacific.

I have long been actively interested in the study of variations in weather due to variations in the frequency, intensity and tracks of storms and the possible causes and effects of such variations. A field study of the effects of tropical cyclones was made in the West Indies in 1915; statistical studies, in 1920. In 1920 and 1921 the possible important effects of variations in storminess upon ancient climates were considered in some detail (89).

The present paper is based on field work which was done while on a leave of absence from Indiana University during the year 1921-1922. Stays of a month or more were made in Hawaii, in Fiji, in southeastern Australia, and in the "Far East," and at each place information was gathered from many sources, and the problems were discussed with scientists, government officials, and other persons.

In writing this paper, four main objectives have been kept in mind: (1) the gathering of data concerning the occurrence of the tropical cyclones of the Pacific; (2) the study of these storms, and related storms elsewhere, with a view to arriving at a fuller understanding of the origin and characteristics of tropical cyclones; (3) gathering facts regarding the effects of Pacific tropical cyclones upon life, and also regarding methods by which their damage may be reduced; (4) a consideration of additional ways in which these storms may have influenced life directly and indirectly.

The inadequacy of current knowledge about tropical cyclones is evident. Their occurrence is very imperfectly known and recent leading textbooks in meteorology, for example, contain many erroneous statements on this subject, such as the assertion that cyclones develop only on the western

[1] Figures in parentheses refer to bibliography on pages 157-163.

sides of the oceans. A treatise only a little more than a decade old, in discussing the number of tropical cyclones occurring annually in the world, ignores those of the Southern Hemisphere. The general movements of normal storms are known in a general way, but why the storms travel as they do is not clearly known. Several theories as to place of origin have been offered and a number of suggestions as to the manner of origin of the storms, but most of these are disproved by data now available. Even the most satisfactory theory of origin leaves much to be desired, as it does not explain the marked variation from year to year or from place to place in the number of cyclonic disturbances and other important features. The inadequacy of current knowledge is strikingly illustrated by the statements given in even the best of recent meteorological treatises in regard to the frequency and the courses of the storms. For instance, one of the best recent treatises states that only two or three a year pass northward out of the Tropics. Instead of being rare phenomena, confined only to very small areas, tropical cyclones of varying degrees of intensity occur, on the average, in excess of a hundred each year, and a large share of the world is appreciably influenced by them several times a year.

As recently stated by Sir Napier Shaw (164), one of the great hindrances to an understanding of world meteorological conditions is the lack of sufficient knowledge of tropical cyclones. A fuller knowledge of cyclones has obvious advantages for residents in the Tropics as well as for investors and navigators concerned with reducing the repeated heavy losses resulting from these storms. For example, the Galveston, Texas, disaster of 1900, with its loss of six thousand lives and its property loss of over thirty million dollars, led that city to follow the advice of experts and to protect itself from similar storms by building a great sea wall and by raising the level of the lower parts of the city. These efforts were so successful that a subsequent hurricane (that of August 17, 1915) of even greater severity caused comparatively little damage.

IMPORTANCE OF TROPICAL STORMS

Tropical cyclones differ widely in their intensity and in their effects. The more severe hurricanes and typhoons are terrible storms, some of which cause great destruction of life and property. For example, the Swatow typhoon of August 23, 1922, is said to have caused the death of over fifty thousand people (169) but other equally severe storms do little damage, the difference depending largely on the course the storms follow. Most tropical cyclones, however, are not of the exceptionally severe type. Instead of being accompanied by winds which blow at the rate of more than a hundred miles an hour, the average tropical cyclone has winds of

from forty to seventy miles an hour. Many cyclones, less intense, are not accompanied by gales.

The importance of tropical cyclones depends on several factors besides the strength of the wind. They commonly yield rain, often very welcome rain, and produce a radical change of the weather. These weather changes and the fear aroused in those individuals who notice the approach of a cyclone of unknown severity, are the source of appreciable psychological effects. A disastrous storm may cause profound economic and social demoralization in the damaged tracts and associated areas. The effects of these cyclones upon the fauna and flora also are striking. (See p. 119.) Many of the storms travel for thousands of miles, carrying vast amounts of latent energy from lower latitudes into somewhat higher latitudes. Sometimes debris and many living organisms are transported and weather conditions far from the Tropics affected. But apart from their effects on life and weather, tropical cyclones merit scientific study as natural phenomena.

ACKNOWLEDGMENTS

The field studies on which this paper is based were undertaken in consequence of my appointment as Bishop Museum Fellow in Yale University for the year 1921-1922. In addition to the fellowship funds, financial assistance for travel and subsequent study was given by Indiana University and Bernice P. Bishop Museum. Encouragement and helpful information were given by many individuals. During the course of field work valuable conferences were held with Mr. L. H. Daingerfield, Observer, United States Weather Bureau, Honolulu; with Mr. H. A. Hunt, Director, and Mr. David Hodge, Mr. E. T. Quayle, and Dr. A. Kidson of the Central Office, Commonwealth Bureau of Meteorology; with Mr. A. Bond of the Brisbane Office; with Captain Wallace Wilson of Levuka, Fiji; with Father José Algué, S. J., Director of the Philippine Weather Bureau, Manila; with Mr. T. F. Claxton, Director of the Royal Observatory, Hongkong; with Father Louis Froc, S. J., Director of the Zikawei Observatory, Shanghai; with Dr. T. Okada, Director of the Japanese Imperial Marine Observatory, Kobe; and with Dr. T. Saki, Acting Director of the Meteorological Bureau, Tokyo.

Since returning to the United States mainland, I have conferred or corresponded concerning tropical cyclones with Dr. O. L. Fassig, United Weather Bureau, San Juan, Porto Rico; Professor Ellsworth Huntington, Yale University; Professor Charles F. Brooks, Clark University; and with Mr. Willis E. Hurd, Mr. F. G. Tingley, Mr. C. F. Talman, Mr. C. L. Mitchell, and Mr. A. J. Henry, of the United States Weather Bureau.

Especial acknowledgments are due Mr. Clifford M. Zierer, graduate student and Assistant in Geography at Indiana University, 1922-1923, for his aid in compiling lists, tables and charts. Professor Brooks, Professor Huntington, Mr. Hurd, Mr. Mitchell, Mr. Tingley, and Mr. Zierer have been so kind as to read most of the manuscript and to offer helpful suggestions. Others who have performed the same valuable service are Professors E. R. Cumings, Frank Davidson, and W. M. Tucker, of Indiana University, Professor Herbert E. Gregory of Yale University, and Professor J. Russell Smith of Columbia University. I am indebted to Dr. W. J. Humphreys of the United States Weather Bureau for critical reading of those parts of the manuscript dealing with technical description, and with origin and energy of cyclones.

TROPICAL CYCLONES AND THEIR EFFECTS

ELEMENTARY DESCRIPTION

Tropical cyclones are similar in many respects to the lows or cyclones of middle latitudes. Both are characterized by central areas of comparatively low barometric pressure toward which the wind blows more or less spirally; both are accompanied by cloudiness and at least local precipitation; both move rather slowly, normally in a more or less characteristic direction; both vary greatly in intensity; both occur in all months of the year, but are more frequent and stronger in one season than in another. Some tropical cyclones cause merely slight changes of the weather; others are accompanied by strong winds; still others by gales; and a lesser number by winds of hurricane force. In several minor respects, however, tropical cyclones differ from the lows of middle and high latitudes. On the average they are more intense: relatively few extra-tropical lows are accompanied by gales, and very few have winds of hurricane force (75 miles an hour, 33 meters a second, exerting a pressure of more than 16 pounds a square foot) (162). On the other hand, gales are so common in connection with tropical cyclones that seamen ordinarily do not speak of a tropical cyclonic disturbance as a "hurricane," "typhoon," or "cyclone" unless winds of gale force are present, although in so restricting the use of the term "cyclone" they certainly err. Winds of hurricane force occur during the life of perhaps one-fourth or one-sixth of tropical cyclones, and in perhaps one-half of all the well-developed storms. Mitchell (126), however, reports that fully one-half of all West Indian cyclones develop winds of hurricane violence.

Another notable difference between the cyclones of low latitudes and those of middle latitudes is the direction of average movement. Tropical cyclones usually move westward or poleward but they sometimes move in the opposite direction; mid-latitude cyclones practically never move westward nor into the tropics. In other words, many tropical cyclones move out of the tropics, but no mid-latitude lows become tropical cyclones.

Differences in the average size and shape, and in velocity have been emphasized by some writers, but the difference relates only to averages, exceptions being numerous. The isobars of most tropical cyclones are more nearly circular than the isobars of extra-tropical cyclones and most tropical cyclones, too, are smaller than their prototypes of higher latitudes,—averaging about 300 or 400 miles across, as compared with perhaps twice that diameter. They also move more slowly than most mid-latitude cyclones. Their average rate is about 300 miles a day, about half that of

extra-tropical cyclones; but tropical cyclones differ widely in size. Some of them have almost no effect on the weather of places more than 50 miles from the center of their path, while others produce gales simultaneously in a belt over 600 miles wide.

The shape of most mid-latitude cyclones is elliptical, and of most tropical ones nearly circular; but of many the converse is true. A few tropical cyclones are pear-shaped. Although most storms in the Tropics travel about 300 miles a day, a few move even 400 or 500 miles, some much more slowly, even less than 100 miles a day.

Another difference between tropical and extra-tropical cyclones is the so-called "eye of the storm"—a calm central area, usually with a diameter of 10 to 20 miles. Points over which the "eye" passes experience a radical change, the wind dying down for a period of perhaps an hour and then coming up equally strong from the opposite direction. In mid-latitudes very few cyclones have a distinct "eye."

Tropical cyclones are most closely comparable with the lows of mid-latitudes, but they may be also advantageously compared with tornadoes and with dust whirlwinds, which are also cyclones, although differing in origin and in other respects. By imagining a dust-whirlwind magnified until its diameter is an eighth of a mile or so, a fair idea of a tornado may be obtained. If a dust-whirlwind or a tornado were scores of miles across instead of a few feet or rods across, it would appear much like a tropical cyclone. Both dust whirlwinds and tornadoes resemble tropical cyclones in the irregularity of their movement, and their greater frequency during some one season. Tropical cyclones differ from tornadoes, however, in several respects. Few tornadoes are destructive over a belt wider than a quarter of a mile and longer than thirty miles, but hurricanes and typhoons may cause great damage throughout a belt several hundred miles wide and a thousand miles long. But the wind within tropical cyclones is nowhere as strong as within a typical tornado. Instead of twisting off trees and demolishing buildings in their path, as the well-developed tornado does, a hurricane usually uproots a few trees, breaks off branches and strips off the leaves, and generally demolishes only the less substantial houses. Tornadoes are most frequent in spring and early summer; tropical cyclones may occur in every month of the year, although 80 or 90 per cent develop during the summer and autumn. Briefly, tropical cyclones are great whirls, averaging about 300 miles across, which develop usually within latitudes 10 to 25 degrees north and south of the Equator, and commonly move slowly westward or poleward, or both westward and poleward. Some storms go westward for a long distance before they turn towards higher latitudes, but others move almost due north in the

Northern Hemisphere, or south in the Southern Hemisphere. Many pass out of the Tropics and then move eastward, soon becoming indistinguishable from a low that has originated in mid-latitudes. A few storms go in a direction opposite to the normal, and many lose their strength before reaching high latitudes. The normal courses of storms and also the wide departures from normal, which sometimes occur, are clearly shown in the charts of typhoons (fig. 10). Although destructive tropical cyclones are rare within about 10 degrees of the Equator, they have been known to be very destructive within 5 degrees. Indeed, cyclonic gales are not unknown on the Equator itself. (See p. 83.)

The local evidences of the approach of a hurricane are a pronounced fall in the barometer, a thickening of the weather, and an increase in the wind velocity. A fall of the barometer half an inch below normal is not

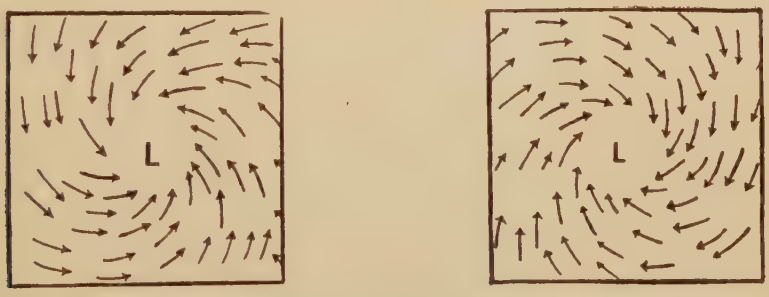


FIGURE 1.—Diagram showing the directions followed by wind spiraling into cyclones: a, Northern Hemisphere; b, Southern Hemisphere. L indicates the storm center.

unusual and at and near the storm's center, a fall of more than two inches occasionally occurs. The direction in which the storm is moving is indicated by the direction of the wind. Since the wind blows spirally towards the center of the low, clockwise in the Southern Hemisphere and counterclockwise in the Northern Hemisphere, a storm in the Southern Hemisphere, coming from the east is signalized by a southerly wind on its front; one approaching from the north has easterly winds on its front, and one coming from the west has northerly winds. In the Northern Hemisphere a storm coming from the east has northerly winds on its front, and one coming from the south has easterly winds. (See fig. 1.)

Little change in direction of the wind, and continuous rapid fall of the barometer, indicate that the storm is coming straight on. Steady shifting of the wind indicates that the center will pass to one side of the observer. For storms coming from the east (in the Northern Hemisphere), a shift in the wind direction from north to northeast and then to east indicates that

the center is passing on the south. Conversely a shift from northerly to westerly indicates that the center is passing on the north. If the center is passing over the observer, the wind dies down suddenly, only to spring up from the opposite direction with the same violence as before the calm as soon as the center has passed. The duration of the calm depends on the size and rate of movement of the storm and whether the full width or merely a chord of the vortex of the storm passes over the locality. The maximum duration of calm is rarely more than two hours. A progressive rise in the barometer indicates that the storm is passing away. With eastward moving storms the wind shifts from south to west, and then to northwest as the center passes to the north. If the center passes to the south, the wind shifts from south to east and then to northeast. In the Southern Hemisphere the wind directions are the opposite to those noted for the Northern Hemisphere.

Although the most striking characteristic of tropical cyclones is the strong winds spiralling towards the center, the destructiveness of these storms is only in part directly due to the winds. Indirect results of the wind commonly do more damage than the wind itself. Waves produced by the wind engulf boats, break them, or drive them upon the shore, and may do great damage upon low-lying coasts. Wall-like waves five or ten feet in height, advancing far up the streams, may drown people miles from the sea. The destructiveness of the waves along the shores is greatly increased by the rise in the sea level itself, which occurs near the center of the storm, due both to the wind-driven water of the inrolling waves, and, in a lesser degree, to the partial vacuum at the center. Indeed, the sea level itself is sometimes raised more than 10 feet, and waves reach heights of 20 feet or more above normal sea level. For example, waves rose 46 feet above sea level during a typhoon at Mille, latitude 8° N. in the Marshall Islands, June 30, 1905 (140, p. 541). Low-lying lands have repeatedly been overswept by hurricane waves. Reports indicate that the only surviving residents of certain low islands were persons who had climbed palm trees and tied themselves there. Imagine being lashed about for hours by wind of hurricane force, expecting any moment that the slender trunk would break or that the tree would be uprooted by the wind, or by the waves dashing beneath!

The partial vacuum, characteristic of the center of severe tropical cyclones, and which is the result of the difference in air pressure at the center of the storm and at its margin, is a contributory cause of the elevated sea level. When the pressure difference is an inch, the sea level at the center is raised about a foot, and when the pressure at the center is less than twenty-eight inches a condition that occurs rather frequently,

the sea level is raised about two feet. As a consequence, the waves advance much more rapidly and farther upon shelving coasts. When the center of a hurricane strikes a low coast at the time that a high tide is coming in, the effects of the waves are intensified. The great difference in the height to which hurricane waves from a given storm or from storms of similar intensity reach upon two similar coasts, is often due to the fact that the storm happened to strike one coast during high tide, and the other at low tide. When the range between high and low tide is several feet, the effects of hurricane waves of similar height may be very different.

Another cause of destruction by tropical cyclones is the downpour of rain commonly associated with these storms. As much as 20 inches of rain may fall in a day or two, while the storm is passing. Indeed, there are several official records of over 50 inches in three days (193, 196). As a result, small streams swell into dangerous torrents, and much low-lying land is flooded. Furthermore, the destruction when the flood abates, the pools of stagnant water left in the flood-worn hollows, the numerous dead animals, and the impoverishment of many people in the damaged area, all tend to increase disease. Starvation may follow. (For descriptions of experiences during the passage of tropical cyclones see pages 147-156.)

But tropical cyclones are not wholly detrimental. They induce most of the rainfall in many regions which otherwise would be dry, as the leeward sides of mountains in the Trade Wind Belt (176). They encourage alertness and preparedness in a climate where man is likely to be carefree. The changes they produce in an otherwise monotonous climate tend to stimulate people to activity. They encourage not only forethought and preparation, but scientific research and widespread cooperation. (See p. 139.) Hence, tropical cyclones are illustrations of the great rule that every force and happening in nature has both favorable and unfavorable aspects.

TECHNICAL DESCRIPTION

GENERAL CHARACTERISTICS

A tropical cyclone is a whirl formed in and carried along by a current of air. Its winds are the result of the simple gyration superposed upon the movement of translation within the general air current. Therefore, wherever the velocity of translation is slow, the air plainly circles about the center of the vortex, but wherever it is rapid, as it frequently is in mid-latitudes, the gyratory movement of the air is not very apparent.

During the earlier stages of their development, tropical cyclones rest upon a thermal basis. Their initiation is intimately associated with abnormal temperature gradients which occasionally extend locally to great

heights. Shaw (164) has pointed out that wherever the air has a temperature of 80° F. (26.7° C.) and is saturated, it needs must rise to a height of 10 miles (17 km.) before it is in equilibrium with the surrounding air. The outflow of air above such a warm, humid area increases the pressure in the surrounding region, thus tending to produce inblowing surface winds. Under favorable conditions, a gyration is inaugurated. (See p. 90.) After the gyratory movement is well started, the storm becomes a separate dynamic entity, subject to the laws of gyrostatic phenomena, instead of to the laws that controlled it while it was on a thermal basis.

In contrast to the cyclones of middle latitude, most tropical cyclones have a calm central eye, higher average wind velocities, a slower rate of translation, and less contrast between the quadrants in respect to temperature. They are smaller and more nearly circular, on the average, and have lower pressures at their centers. They also normally yield more precipitation in a given period.

THE EYE OF THE STORM

The central eye or vortex is probably the most distinctive feature of tropical cyclones. Within the Tropics it is rarely absent but it nearly always disappears as the cyclone passes to higher latitudes. The larger mid-latitude cyclones very seldom have an eye, although a decided decrease in wind velocity at the center is common. The small whirls, tornadoes and dust whirlwinds, however, possess a calm center, corresponding to the tropical vortex.

The following summary is based on studies by Ballou (10), and by Chu (31).

In most tropical cyclones the wind velocity increases until just before the calm sets in, but in a few storms the decrease commences some distance from the central calm. After the calm has passed, the wind suddenly increases to almost maximum velocity, coming, however, from the opposite direction.

In most cyclones the calm is almost complete, but records reveal several instances in which light variable breezes or squalls occurred during the passage of the "eye" of the storm.

The waves of the sea are always high, confused and dangerous near the center of the storm because of the rapidly changing direction of the wind, and the meeting of waves from different directions.

For the average storm, the duration of the calm is 20 to 40 minutes, but in about one-sixth of the cyclones concerning which this information

is available, the duration is more than an hour, and in one recorded by Ballou, it lasted eight hours.

The mean diameter of the calm area is about 14 miles (23 km.), but storms differ widely in this respect.

In the central calm, the rain ceases, and the clouds almost disappear. A light mist with clearings is common, but thick banks of clouds usually surround the horizon.

Within some calm centers the barometer is absolutely steady throughout, in others the barogram shows a very distinct minimum at the beginning of the calm and then a continuous rise. Some barograms show sudden oscillations near the beginning and end of the calm, and uniform pressure during the remainder. Others show continuous oscillations throughout,

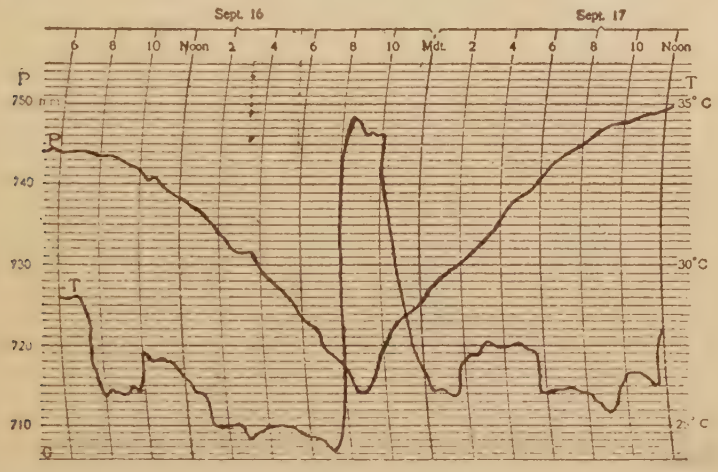


FIGURE 2.—Diagram of barograph and thermograph curves at Taito, Formosa, September 16-17, 1912, showing a sudden rise in temperature as the storm center passed, after sundown. (After Chu, Monthly Weather Review, vol. 46, p. 418, 1918.)

and yet others show a continuous fall in pressure from the beginning to the end of the calm. Most barograms show a distinct minimum about the middle of the calm.

The relatively few storms for which data concerning changes, temperature, humidity and pressure have been obtained, show in these features a lack of uniformity. In several storms the temperature rose sharply during the calm, and the relative humidity fell correspondingly. A "burning wind," like the Italian sirocco, was felt when the center of a typhoon passed over the Manila Observatory on October 20, 1882. But in other typhoon centers, no rise of temperature or fall in humidity was observed. Hence, there has been some uncertainty as to the cause of the observed

changes in temperature and humidity. Chu found published accounts of four typhoons of the years 1904 to 1915 inclusive, in which there was a clear record of an increase in temperature during the passage of the calm. In one storm of exceptional severity the calm passed the observatory at Taito, Formosa, between 8 p. m. and 9 p. m., and the recorded rise of 19° F. (10.5° C.) could not have been due to insolation during the comparatively clear calm. A copy of the barograph and thermograph record of this storm is shown in figure 2.

Chu (31) records two typhoons in which a distinct rise in temperature took place during the calm at sea and concludes that there is almost cer-

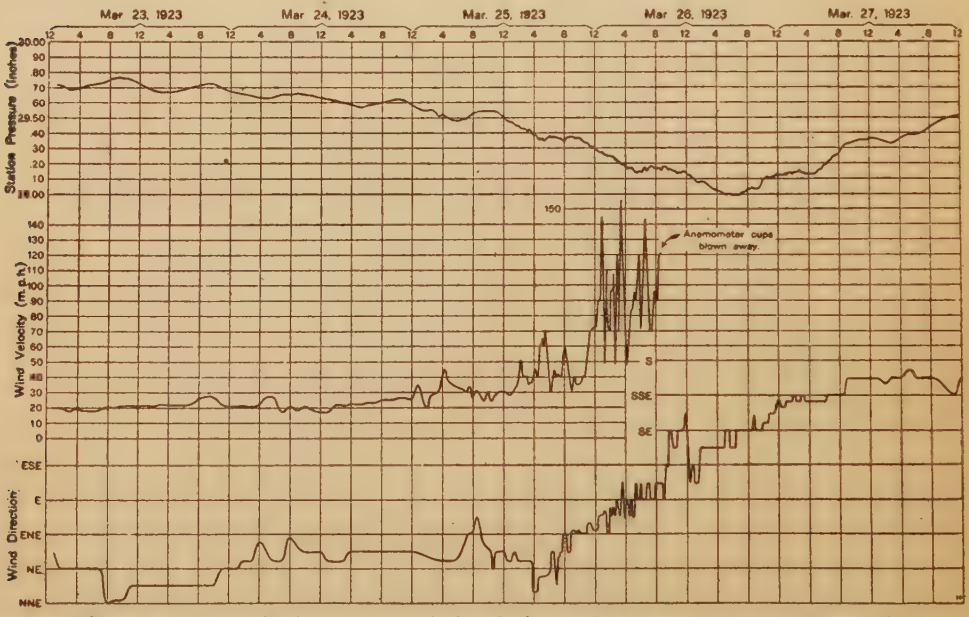


FIGURE 3.—Record of pressure, wind velocity and wind direction at Guam (latitude 13.42° N., longitude 145° E.) during the passage of a typhoon in March, 1923. Special features indicated are the sudden changes in the wind, and a velocity of more than 140 miles an hour attained while the pressure was still above 29.10 inches. (After West and Swartout, Monthly Weather Review, vol. 51, p. 463, 1923.)

tainly a gentle descending current of air in the eye of the storm. This current causes the disappearance of the clouds and the rise in temperature during the night, as well as that part of the rise occurring during the day, which cannot be attributed to the warming by the sun during the time of clear sky.

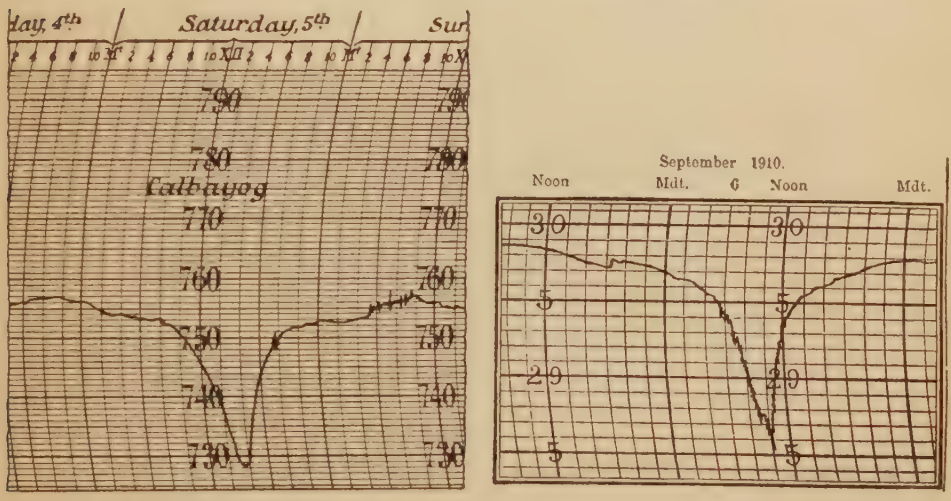
QUADRANT TEMPERATURE DIFFERENCES

The slight contrast among the quadrants in surface temperature has been mentioned as a distinctive characteristic of tropical cyclones. It

applies more especially to storms near the Equator; for there, winds from all directions have similar temperatures, because the horizontal temperature gradients are slight, and the storms relatively small. Not many degrees from the Equator, however, quadrant temperature differences appear, for winds coming from higher latitudes are cooler than those coming from lower latitudes. By the time the tropical cyclone has reached the margin of the Tropics, the temperature contrasts among the quadrants are almost as great as those of mid-latitude cyclones in summer. This is especially true if the tropical cyclone has enlarged considerably, as it commonly does, and involves the air over an area comparable with that of a medium-sized mid-latitude cyclone.

DISTRIBUTION OF PRESSURE

Four aspects of the distribution of pressure may be mentioned: (1) the outer ring of high pressure; (2) barometric gradient; (3) the pumping of the barometer; and (4) minimum pressure.



(*a*) (*b*)

FIGURE 4.—Barograph records: a, Calbayog, Philippine Islands, December 4 and 5, 1908, showing "V" shape as the storm center passed, and the ring of higher pressure some distance from the center (Philippine Meteorological Bulletin, December 1908); *b*, Turnabout Light, China, September 6, 1910, during the passage of a typhoon, showing marked "pumping" of barometer. (After Froc, Bulletin of Zikawei Observatory, 1910.)

Surrounding the normal storm is a zone, a hundred miles or more wide, in which the pressure is above the normal for the season, locality, and the time of day. For many storms it is as much as two-tenths of an inch (5 mm.) higher than normal. Such an excess is sufficient to overcome the normal diurnal change of pressure. It is the result of the superposition of

the air that has risen within the storm area and flowed out at a high altitude. (See fig. 4 and fig. 6.)

The barometric gradient is steep in the normal tropical cyclone. It is illustrated for several storms in figures 2, 3, 4, 5, and 6. Moreover, the velocity of the wind with a given barometric gradient is greater, on the average, in the Tropics than in mid-latitudes, in part because of the greater absolute humidity of the air in the Tropics, which permits a freer air movement than in mid-latitudes (45, 197); and in part because of the lesser deflective effect of the earth's rotation.

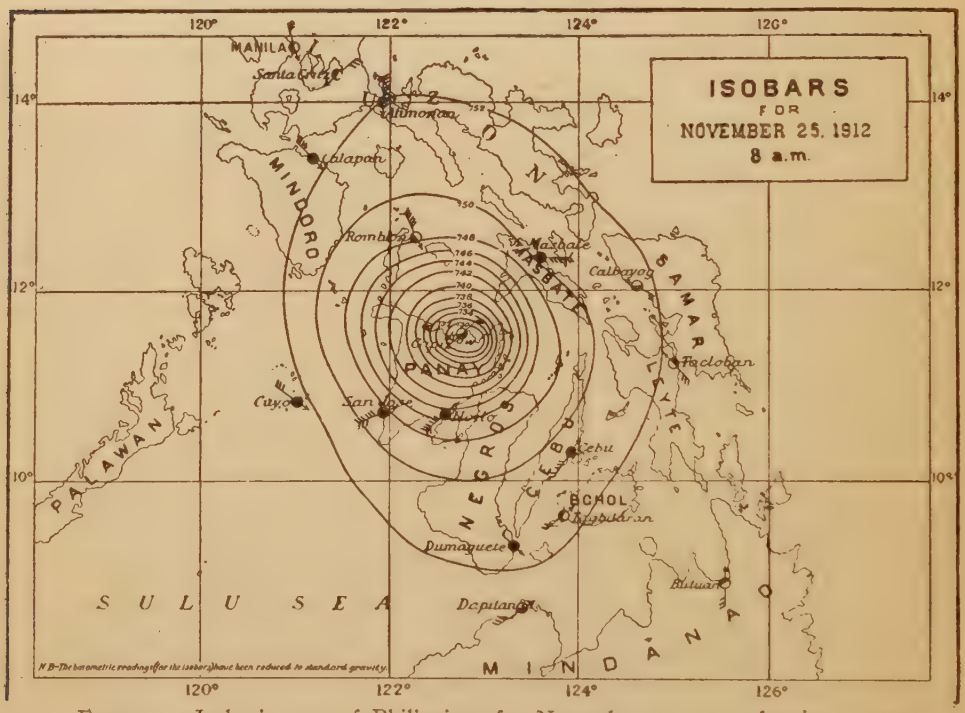


FIGURE 5.—Isobaric map of Philippines for November 25, 1912, showing a severe typhoon. (Philippine Meteorological Bulletin, November, 1912, p. 401, 1913.)

The "pumping of the barometer" is shown by barograms of different storms (figs. 4, 6). Several influences doubtless assist in causing the irregular changes of pressure shown. Four of these are: (1) strong gusts of wind; (2) occasional presence of secondary centers; (3) local rapid condensation and precipitation, temporarily reducing the pressure below the average for that position in the storm; (4) the normal semi-diurnal changes of pressure which are usually well marked within the Tropics.

Barometric minima below 29.5 inches (1,000 millibars) are common in the centers of tropical cyclones. In most storms, minima of less than 29

inches occur, and for many pressures as low as 28 inches (948 millibars) have been recorded. A few lower pressures are recorded. For example, during one decade, five of the typhoons which crossed the Philippines had minimum pressures below 27.6 inches (935 millibars). (See p. 85.) Figure 6 shows barograph records of one of them, in which the pressure

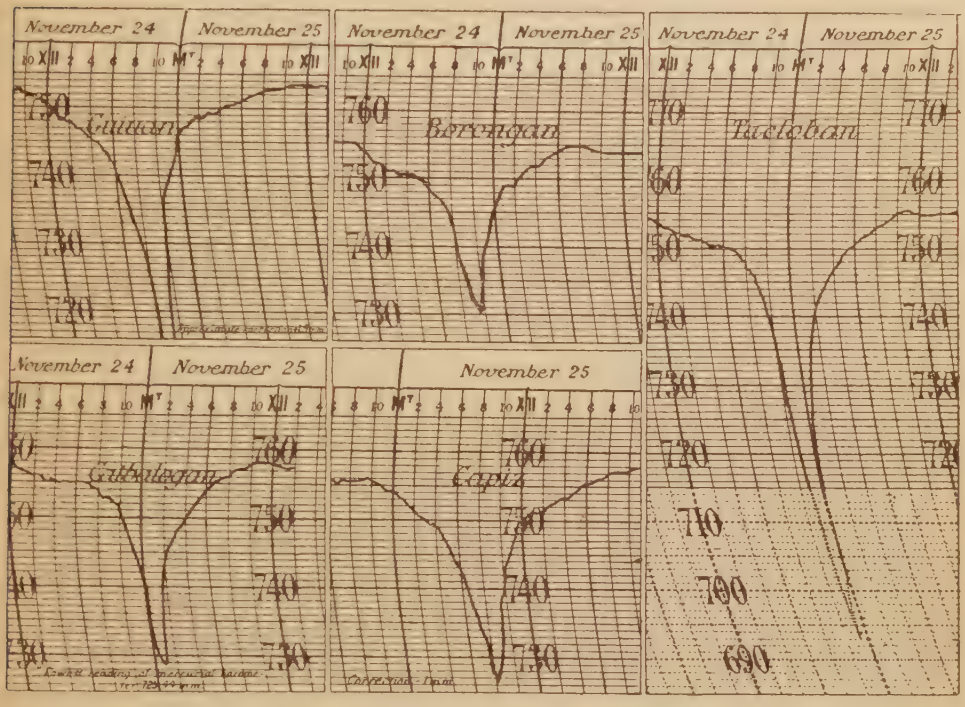


FIGURE 6.—Barographic records of the severe typhoon of November 20-28, 1912, including a minimum of less than 700 mm. (Philippine Meteorological Bulletin, November, 1912, p. 401.)

fell to a little less than 27 inches. There are also a few apparently trustworthy records of minima of about 27 inches in hurricanes of the South Pacific and Australia, and elsewhere.

SHAPE

Most tropical cyclones are elliptical, the ratio between the longest and the shortest diameter being about three to two. The elongation is normally in the direction of travel, although it may be at any angle. Many tropical cyclones, however, are nearly circular; and a few, at least in the Philippine region and the western South Pacific, contain secondary centers, and thus have an irregular shape. According to evidence gathered by

Captain Wallace Wilson of Levuka, Fiji, the Fijian hurricane of January 21, 1904, apparently was distinctly pear-shaped. Algué, Froc, and Okada informed me that secondary centers are not infrequent in typhoons; but Mitchell writes me that he has found no proof of such an abnormality in West Indian hurricanes.

DIRECTION OF WINDS ABOUT THE CENTER

As the wind spirals inward towards the center, it does not follow the isobars. Thus the angle between the wind and a line connecting the center and the observer is less than a right angle, usually, in fact about thirty degrees less, varying with the quadrant. The isobars are followed somewhat more closely by the wind near the center of the storms than farther away. Claxton (33) reports an average angle of 20.5 degrees between the wind and the isobar within 100 miles from the center, 36.5 degrees at 100 miles, and 47.5 degrees at a distance of 200 miles from the center. In one quadrant, the angle with the isobar may be 35 degrees to 40 degrees; while in the opposite one it is 20 degrees to 25 degrees. The quadrant having the greatest angle is usually the northeast in the Northern Hemisphere and the southeast in the Southern Hemisphere, but the direction in which the storm is travelling causes irregularities.

Sudden slight changes in wind direction are frequent in tropical cyclones, each new gust coming from a different direction. Some changes in direction of this type are related to the progressive shift in direction that occurs as the storm passes, and others are caused in part by local rain squalls, by convection currents, and obstructions. The descending currents of the squalls have a different direction and velocity than the winds that have been affected by surface friction for some time. Claxton (33) gives the following illustration of the shift in wind direction as a storm passes to the south of the observer in the Northern Hemisphere.

Direction of Storm Center	ESE	SE	SSE	S by E	S	S by W	SSW	SW	WSW
Angle between wind and direction of center									
Points	4.4	7.6	10.5	11.0	10.1	9.9	10.3	11.8	13.0
Degrees	49.5	84.5	118.1	125.	113.	111.3	115.9	132.7	146.2

LOCATING THE STORM CENTER AND PREDICTING ITS MOVEMENT

Most mariners encountering a tropical cyclone are desirous of locating as closely as possible the position of its center. The methods used when observations are obtainable only from a single ship are discussed in nautical sailing directions. The diagrams (figs. 7, 20) assist in visualizing the method of obtaining the direction of the center from the direction of the wind. The distance to the center may be estimated from the strength of

the wind and the rate of fall of the barometer, but this method is rendered decidedly unsatisfactory by the great variation in the size, intensity, and rate of movement of storms. Reports from other stations, by radio or telegraph, are highly desirable if the position of the center is to be located.

Froc (65) gives a striking illustration of extreme contrast among typhoons in respect to size, and hence, indirectly, of the difficulty of estimating the distance to the center from any particular point of observation. One destructive typhoon had no obvious influence on wind or pressure at

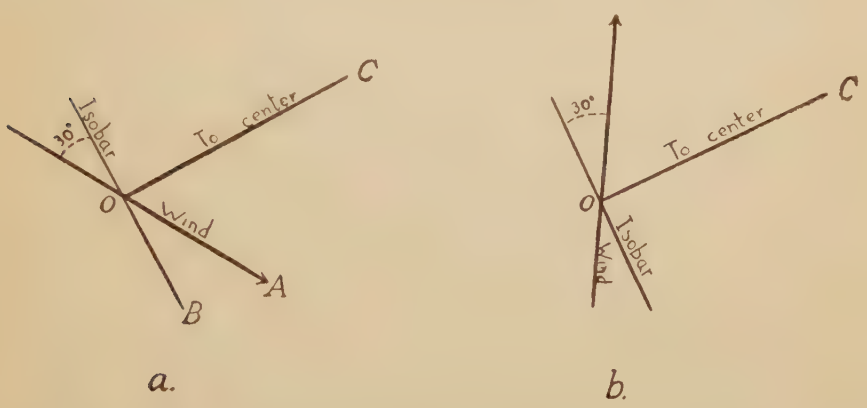


FIGURE 7.—Diagrams showing method of locating the storm center from the direction of the wind: a, Northern Hemisphere, northwest wind blowing; b, Southern Hemisphere, south-southwest wind blowing; both a and b, storm moving westward somewhat to the north of the observer at "O" and storm center northwest of observer.

a meteorological observatory only seventy-five miles from the center of its track, while another typhoon produced gales throughout a belt eighteen hundred miles across. In respect to the larger of these storms, it is probable that the simultaneous gales over so large an area were not entirely due to the typhoon, but were a combination of cyclonic and monsoon winds. At certain times the only thing necessary to convert the northeast monsoons along the China coast into gales, is a large, intense cyclone at the south to somewhat increase the gradient.

Several forces affect the movement of the storm, and a successful prediction of its future course requires a knowledge of pressure and wind conditions over a considerable area. A single competent observer near the storm's center may, however, successfully predict the course the storm will take during the next few hours. One criterion of value is the direction of the movement of the clouds of the zone in which condensation is most active, for the movement of the winds in that zone, where the storm receives most of its energy, largely controls its movement. These higher

winds may carry the storm across or even against shallow surface winds. Another criterion is the inclination of the vertical axis of the storm. Algué told me that in his opinion the vortex of the storm is always tipped in the direction in which the storm is about to move. For courses followed by storms, and the reasons for these courses, see detail on pages 66-80.

ASSOCIATED PHENOMENA

Accompanying the steep barometric gradient and strong winds of a tropical cyclone are several other phenomena, including clouds, rain, lower temperatures, often lightning, and sometimes waterspouts. The clouded area, incident to most hurricanes is more extensive than the area over which surface gales prevail—for many it is twice as extensive. The outermost zone of clouds is characterized by light, feathery plumes of high cirrus clouds radiating from the storm's center. Nearer the center, the sky is covered with a uniform cirrus veil. Halos are visible around the sun by day and around the moon by night, and red and violet tints at dawn and sunset. A fine misty rain sometimes falls. In the zone nearer the center, the sky is overcast, and the rain falls in torrents. In the "eye of the storm" there are few clouds.

The fall in surface temperature characteristic of tropical cyclones is due to the cloudiness, to the cooling effect of the relatively cold rain, to the strong winds, especially those from higher latitudes, and also to the evaporation of ocean spray and the cooling of the surface waters by evaporation and mixing.

Lightning is very severe in some hurricanes but is almost lacking in others, being lacking where the air has been ionized and hence unable to accumulate electricity. The reasons for these differences in ionization apparently are related to the location of the storm with respect to the area of its origin, near which the air is humid to great height and is commonly ionized. After the storm has traveled a considerable distance, the air is not humid to such great heights and often is not well ionized, and hence the electricity generated during the formation and fall of the rain accumulates in the clouds until discharged by lightning.

Waterspouts represent local whirls of great intensity. There are many records of waterspouts forming just before the beginning of storm gales, and a few accounts of waterspouts during the storm. Upon the ocean a strong swell is set up by the hurricane winds. This swell commonly travels outward faster than the storm advances, and therefore may afford warning to observers at considerable distances away. The direction of the swell indicates the direction of the storm center at the time the waves are propagated, but not its position at the time that the waves reach a distant point, for, in the meantime, the storm has moved.

DISTRIBUTION AND FREQUENCY OF TROPICAL CYCLONES

AREAL DISTRIBUTION

There are three chief centers of origin of Pacific tropical cyclones: (1) Western North Pacific (the "Far East"), between the Marshall Islands and China. Within this area, most of the tropical cyclones, there called "typhoons," originate some distance east of the Philippines in latitudes 8° to 25°; (2) the Western South Pacific, especially between Samoa and Australia, in south latitudes 10° to 25°; (3) the Eastern North Pacific off the west coast of Mexico and northern Central America in north latitudes 10° to 25° and longitudes 90° to 140° W.

In addition to these areas of rather numerous storms, tropical cyclones occasionally develop in four other regions: (4) near Hawaii and elsewhere in the vast expanse between longitude 140° W., and the Marshall Islands, longitude 170° E.; (5) many cyclones also reach the Pacific after having crossed part of Australia; (6) a few tropical cyclones originate nearer the Equator than the main areas outlined as 1, 2, and 3, especially in the East Indies; (7) information concerning the tropical portion of the eastern South Pacific, is very meager, but it is known that tropical cyclones are not entirely lacking there.

Tables 1, 2, 3, and 4 indicate the approximate area of origin or first record of storms in the Western North Pacific ("Far East"), the Eastern North Pacific, and the Western South Pacific, including eastern Australia. Table 1 is based on Froc's list (65) which lists 620 typhoons, for the period 1893-1918: Table 2 is based on Table 16; Table 3 on Table 8; Table 4 on Table 20. The figure given in vertical columns under each five degree square of latitude show the number of storms in an average year.

TABLE I. APPROXIMATE PLACE OF ORIGIN OR FIRST RECORD OF TYPHOONS IN THE WESTERN NORTH PACIFIC, BY 5° SQUARES

	125-130 E.	130-135 W.	135-140 W.	140-145 W.	Total
20-25 N.....	1	....	....	....	1
15-20 N.....	2	3	3	1	9
10-15 N.....	1	5	3	1	10
5-10 N.....	2	2	....	....	4
Total.....	6	10	6	2	24

TABLE 2. APPROXIMATE PLACE OF FIRST RECORD OF 67 CYCLONES IN THE EASTERN NORTH PACIFIC, BY 5° SQUARES

	135-140 W.	130-135 W.	125-130 W.	120-125 W.	115-120 W.	110-115 W.	105-110 W.	100-105 W.	95-100 W.	90-95 W.	Total
25-30 N.	1	....	....	....	....	....	....	....	....	....	1
20-25 N.	....	....	3	1	1	3	7	1	....	....	16
15-20 N.	....	....	....	2	6	1	8	5	1	....	23
10-15 N.	1	....	....	2	8	4	1	4	2	3	25
5-10 N.	....	....	....	....	....	1	....	....	....	1	2
Total	2	0	3	5	15	9	16	10	3	4	67

TABLE 3. APPROXIMATE PLACE OF FIRST RECORD OF 216 TROPICAL CYCLONES IN THE WESTERN SOUTH PACIFIC, BY 5° SQUARES

	165-170 E.	170-175 E.	175-180 E.	180-185 W.	175-170 W.	170-165 W.	165-160 W.	160-155 W.	155-150 W.	150-145 W.	145-140 W.
5-10 S.	....	....	1	....	1	....	....	....	....	....	2
10-15 S.	1	2	4	5	23	2	1	....	2	....	40
15-20 S.	22	6	50	5	18	....	1	....	4	5	111
20-25 S.	14	14	3	3	4	....	1	1	1	1	42
25-30 S.	3	....	2	1	....	1	1	....	1	1	10
30-35 S.	1	....	2	3	3	....	....	....	1	1	11
Totals	41	22	62	17	49	3	4	1	9	8	216

TABLE 4. APPROXIMATE PLACE OF ORIGIN OF 58 CYCLONES IN EASTERN AUSTRALIA AND ADJACENT WATERS, BY 5° SQUARES

	135-140 E.	140-145 E.	145-150 E.	150-155 E.	155-160 E.	160-165 E.	Totals
5-10 S.	....	....	2	....	....	1	3
10-15 S.	7	3	17	9	22	2	60
15-20 S.	3	1	5	11	23	8	51
20-25 S.	4	2	2	5	21	10	44
Totals	14	6	26	25	66	21	158

LATITUDE OF ORIGIN

According to Tables 1, 2, 3, and 4, more storms are first recorded in latitudes 10 to 15 degrees than in any other five degree belt. The next largest number is in latitude 15 to 20 degrees.

In the Western North Pacific half of the storms appear to start in latitudes 10° to 15°; about a third in latitudes 15° to 20°; and about a sixth in latitudes below 10°. In the Eastern North Pacific, nearly 40 per cent are first reported from latitudes 10° to 15°, and about 30 per cent fall in the next higher zone. Probably many in the large number (one-fourth) that are first reported from latitudes 20° to 25°, actually developed

south of those latitudes, but because of the scarcity of reporting ships and stations, were not promptly encountered. This conclusion is borne out by the fact that only one of the fourteen carefully traced tracks recently published by Hurd (95) originated north of latitude 17°. The exceptional storm originated north of latitude 23° but moved southwestward to latitude 17°—a highly abnormal direction. Half of the storms listed in Table 3 were first recorded from latitudes 15° to 20°, nearly a fifth from latitudes 10° to 15°, and nearly a fourth from latitudes 20° to 25°. In eastern Australia and its Pacific coastal waters, more than one-third originate in latitudes 10° to 15°, and nearly one-third arose in latitudes 15° to 20°. Most of the remainder appear to have arisen in latitudes 20° to 25°.

LONGITUDE OF ORIGIN

According to Table 1, nearly half of the storms in the western North Pacific are first recorded from longitudes 130° to 135° E., and also nearly a half within five degrees east or west of that belt. Two storms in an average year develop east of longitude 140° E. For the Eastern North Pacific three-fourths of the storms indicated in Table 2 apparently originated in longitudes 100° to 120° W. The remaining one-fourth originated either between the main zone and Central America or west of longitude 120°. The five degrees of longitude in which the largest number of storms evidently originate are 105° to 110°, with a fourth of the total number charted.

In the Western South Pacific, the distribution of recorded storms shows a close relationship to the distribution of island groups inhabited by white officials. Table 3 shows marked variations in the number of new storms in different longitudes. The belt in which the Fiji Islands lie (longitudes 175° to 180° E.) has one-fourth of the new storms and includes more than any other, though few more than longitudes 170° to 175° W., in which Samoa lies. A third belt containing more than one-sixth of the storms listed in Table 2 includes the New Hebrides (longitudes 165° to 170° E.). Between these belts of relatively numerous storms there are belts in which few are recorded. This suggests that some storms passing between these groups of islands are not recorded or are thought to be nearer than they actually are to the islands upon which the observer resides.

In eastern Australia and adjacent waters (longitudes 135° to 165° E.), forty per cent of the 158 storms included in Table 4 were first recorded in longitudes 155° to 160° E. This is the midst of the Coral Sea, and represents the region where storms approaching the Queensland coast from the east first strongly affect coastal stations. Many of these storms may have

originated east of longitude 160°, but because of infrequent meteorological reports, remained unannounced until they approached the continent. The increased storminess in latitudes 135° to 140°, at the western margin of the area considered in Table 4, may be due to the effect of the Gulf of Carpentaria. Many storms appear to develop over the western side of this large, almost enclosed body of water.

SEASONAL DISTRIBUTION

Tropical cyclones occur in the Pacific during every month of the year, but are much more numerous during one-half of the year; indeed a large percentage of the storms occur during one-third of the year. Table 5, which gives the monthly percentage for each of the main storm areas derived from lists of hurricanes in the South Pacific, shows that the four

TABLE 5. PERCENTAGE MONTHLY DISTRIBUTION OF TROPICAL CYCLONES

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Number of Storms
W. North Pacific	4.0	1.9	2.3	2.6	5.1	6.1	15.4	16.0	18.3	14.4	8.6	5.3	917
E. North Pacific	1.0	1.0	....	....	....	5.0	11.0	15.0	34.0	24.0	5.0	1.0	95
W. South Pacific	28.7	10.4	25.0	8.0	0.8	0.8	0.4	0.4	0.8	1.6	3.0	12.0	237
East Australia....	18.9	17.1	18.8	10.1	6.9	5.9	5.1	0.4	1.8	3.7	3.2	7.8	217
													Total, 1466

months, July to October inclusive, have nearly two-thirds of the tropical cyclones of the western North Pacific, and four-fifths of those of the eastern North Pacific. In the Southern Hemisphere the four months, December to March inclusive, have between two-thirds and three-fourths of these storms. On the average, September is the stormiest month in the northern Tropics and January in the southern. August and October are the next stormiest months in the Northern Hemisphere and March or February in the Southern Hemisphere. Storms are rarest in February in the western North Pacific, are unrecorded in the eastern North Pacific in March, April, and May, and are very rare in the Southern Hemisphere in August. (See fig. 8.)

FREQUENCY

On an average, more than fifty tropical cyclones develop each year in the Pacific, but most of them are not known to attain hurricane violence. Many of the storms are observed along so small a fraction of their course, or are so inadequately known anywhere, that it is quite impossible to determine how many should properly be classed as hurricanes. In the

western North Pacific the rule is to chart and list all well-developed cyclones, regardless of whether or not they were reported to cause gales.

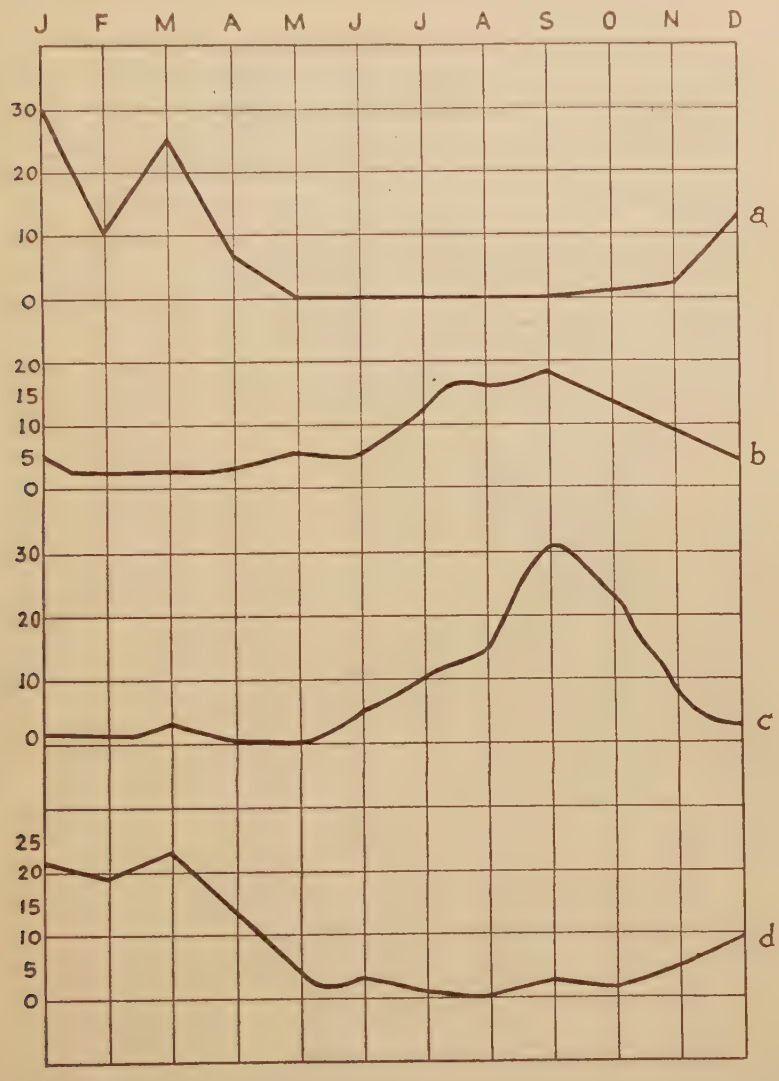


FIGURE 8.—Diagrams showing distribution of cyclones among the months: a, tropical cyclones in the western South Pacific (249 storms); b, typhoons in the Philippine region, 1880-1920 (917 storms); c, tropical cyclones in the southeastern North Pacific (97 storms); d, tropical cyclones in and near Australia (251 storms).

Another difficulty encountered in correctly estimating the number of tropical cyclones, is the incompleteness of the records. Reasonably com-

plete records covering more than a few years are available for only a very small part of the vast Pacific.

Froc's list shows an average of 23.8 tropical cyclones a year in the western North Pacific. From the data presented in Table 13 it appears that two or more tropical cyclones develop each average year in the eastern North Pacific, and from the data given on page 50, it appears probable that three storms a year develop on the average in the middle section of the North Pacific (longitudes 140° W. to 170° E.). Thus there are more than 29 storms a year on the average in the North Pacific ocean alone.

In eastern Australia and along the Queensland coast, there are on the average 15 tropical cyclones a year. About half of that number do not cause damaging gales within Queensland itself, but many of them cause gales at sea. In the western South Pacific (longitudes 160° E. to 140° W.), the records for the individual islands groups, given on pages 31-41 suggest that after due allowance has been made for the incompleteness of the records and for the storms which pass between the islands, perhaps a dozen tropical cyclones develop each average year. Data as to the storminess of the eastern half of the South Pacific are very meager, but it is known that cyclones occasionally develop there. From statistics available it appears probable that the average number of tropical cyclones developing each year in major subdivisions of the Pacific is as follows:

Western North Pacific	23.8	Eastern Australia and Coast	15.0
Eastern North Pacific	2.2+	Western South Pacific	12.0
Middle North Pacific	3.0	Eastern South Pacific	?
Total North Pacific	29.0	Total South Pacific	27.0+

HURRICANES IN THE WESTERN SOUTH PACIFIC

In 1853, Dobson (52) published a list of 24 hurricanes from Pacific island groups, together with some Australian storms, not here considered. In 1893, E. Knipping (106) extended the island list to 120, and 10 more were added in 1897 (48). Schück (158) studied the time and place distribution, and added 5 to the list, bringing it up to 135. In 1920 additional storms were listed by the British Admiralty (20) and the United States Hydrographic Office (188). During a field investigation in the South Pacific, I was able, with the help of many generous residents of different groups, and the assistance of members of the Commonwealth Weather Bureau, to increase the list notably.

The occurrence by island groups and the monthly distribution of tropical hurricanes in the South Pacific from New Caledonia to the

TABLE 6. CYCLONES IN THE SOUTH PACIFIC BY ISLAND GROUPS

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average Annual Frequency
Fiji	21	15	22	5	....	....	....	....	....	....	1	13	77	2
Tonga	16	7	15	6	1	....	....	....	....	....	3	3	51	2
Samoa	10	2	8	2	....	....	....	....	....	....	2	6	30	2-3
N. Hebrides	11	12	9	2	1	....	....	....	....	1	3	2	41	2
N. Caledonia	12	13	10	....	....	....	1	....	1	2	....	5	44	3
Norfolk	5	9	7	3	....	2	....	1	....	2	....	1	30	2
Tuamotus	3	2	1	....	....	....	....	....	1	....	....	....	7	.5
Tahiti	3	1	....	....	....	....	....	....	1	....	....	3	8	.2
Solomon	2	1	2	....	....	....	....	....	....	....	....	1	6	.2
Cook	2	5	3	2	....	....	....	....	....	....	....	5	17	.5
Totals	85	67	77	20	2	2	1	1	3	5	9	39	311	
Percentage.	30	20	25	6	.6	.6	.3	.3	1	2	2.5	12		

Tuamotu Archipelago, inclusive, are listed in Table 6, based on a total of 259 hurricanes. As some storms affected more than one island group, the total given is 311.

The record of storms varies greatly. For certain groups and in certain decades, the information is fairly complete; for others it is fragmentary. The list for Fiji is relatively long, because I spent a month there in 1921 gathering information from observers who reside in different parts of the group, from government records, and from newspapers. The Tonga list comes chiefly from four sources: a short list of especially disastrous storms, supplied by the Premier; a list published by German investigators (48); and a list supplied by Rev. E.

E. Collocott, made up from records of the Tubou College at Nukualofa. Information regarding additional hurricanes at Tonga was gathered from various sources, chiefly from residents in Fiji, and from newspapers in Fiji and Australia. The Samoan list is chiefly that published in the "Segelhandbuch" (48). The lists for New Caledonia and Norfolk Island come chiefly from the Commonwealth Meteorological Bureau. Barometric readings are cabled daily from these islands to Australia, and the Australian Weather Maps include them. I have studied these maps for the thirty years, 1892 to 1921, inclusive. Information regarding the hurricanes of other island groups come chiefly from records published in 1908 and 1920 by the United States Hydrographic Office (188), by the Deutsche Seewarte (48) and by the British Admiralty (20). Data as to a few other storms were obtained elsewhere.

The last column of Table 6 consists of estimates of the probable annual frequency of severe tropical cyclones. It is based upon the decades or series of years for which the information appears fairly complete. For example, for the New Hebrides, during the 26 years, 1867-93, 22 hurricanes are reported, but there is a gap of eight years with no record. On this basis it appears that somewhat more than one hurricane is to be expected annually. But since two storms a year have been recorded in many years, and as the island groups of similar size to the east and west have averages of two or more a year, it seems reasonable to surmise that an average of nearly two storms may be expected to affect some part of the New Hebrides annually. Likewise, although Table 6 lists only seven hurricanes from the Tuamotus, the fact that four occurred in one four-year period and three in another four-year period suggests that hurricanes are not infrequent. Ralph Linton, who is familiar with conditions in the Tuamotus and in the Marquesas, informed me that violent storms occur in both these island groups.

The total of the several estimates of the annual number of hurricanes for all the island groups is 15 storms a year. Perhaps, however, two or three storms cross two or more groups of islands and thus appear more than once in Table 6. Thus the total number of severe tropical cyclones visiting these islands appears to average about 12 a year, but more than 12 hurricanes probably occur annually in this general region, for it is likely that a few unrecorded storms pass between the groups each year, especially between Fiji and the New Hebrides and between Tonga and Samoa and Cook Islands.

The occurrence of recorded hurricanes in the South Pacific by years and by months is shown in Table 7. The monthly occurrence is shown graphically in figure 8.

TABLE 7. RECORDED HURRICANES IN SOUTH PACIFIC, LONGITUDES 160° E. TO 140° W. BY YEARS AND MONTHS

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Month Unknown	Total
1789	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1819	....	....	....	....	....	....	....	....	....	....	....	....	1	1
.. ...	...	....	....	....	1	....	....	....	....	....	....	....	....	1
1830	....	....	1	....	....	....	....	....	....	....	....	....	1	2
1831	....	....	....	....	....	....	....	....	....	....	....	1	....	1
1833	1	....	1	....	....	....	....	....	....	....	....	....	....	2
1834	....	....	....	....	....	....	....	....	....	....	....	....	1	1
1835	....	....	....	....	....	....	....	....	....	....	1	....	....	1
1836	....	....	....	....	....	....	....	....	....	....	....	....	1	1
1837	....	....	....	....	....	....	....	....	....	....	....	....	1	1
1838	....	....	....	....	....	....	....	....	....	....	....	....	1	1
1839	....	1	....	....	....	....	....	....	....	....	....	....	1	2
1840	....	1	....	....	....	....	....	....	....	....	....	2	1	4
1842	....	....	....	....	....	....	....	....	....	....	....	1	....	1
1843	....	....	....	....	....	....	....	....	....	....	....	1	....	1
1845	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1846	....	....	2	....	....	....	....	....	....	....	....	....	....	2
1847	1	....	1	....	....	....	....	....	....	1	....	....	....	3
1848	1	1	....	2	....	....	....	....	....	....	....	2	....	6
1849	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1850	....	....	....	1	....	....	....	....	1	....	....	....	....	2
1852	....	1	1	....	....	....	....	....	....	....	....	....	....	2
1854	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1856	1	....	1	....	....	....	....	....	....	....	....	....	....	2
1859	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1860	1	....	1	....	....	....	....	....	....	....	....	....	....	2
1861	....	....	....	....	....	....	....	....	....	....	....	1	....	1
1862	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1863	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1864	....	....	1	....	....	....	....	....	....	....	....	....	....	1
1865	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1866	....	....	1	....	....	....	....	....	....	....	....	....	....	1
1867	....	1	1	....	....	....	....	....	....	....	....	....	....	2
1868	1	....	....	1	1	....	....	....	....	....	....	....	....	3
1869	3	1	3	....	....	....	....	....	....	....	....	....	....	7
1870	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1871	....	....	1	....	....	....	....	....	....	....	....	....	....	1
1872	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1873	1	....	....	....	....	....	....	....	....	....	....	1	....	2
1874	....	2	....	1	....	....	....	....	....	1	1	....	....	5
1875	3	1	1	....	....	....	....	....	....	....	1	1	....	7
1876	1	1	1	....	....	....	....	....	....	....	....	....	....	3
1877	2	1	2	1	....	....	....	....	1	....	....	1	....	8
1878	2	1	....	....	....	....	....	....	....	....	....	....	....	3
1879	3	....	2	2	....	....	....	....	....	....	....	1	....	8
1880	2	1	1	....	....	....	....	....	....	....	....	....	....	4
1881	....	1	1	....	....	....	....	....	....	....	....	1	....	3
1882	1	1	2	....	....	....	....	....	....	....	....	....	....	4
1883	2	1	2	....	....	....	....	....	....	....	....	2	....	7
1884	1	1	....	....	....	....	....	....	....	....	....	....	....	2
1885	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1886	2	....	1	....	....	....	....	....	....	....	....	....	....	3

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Month Unknown	Total
1887	2	....	1	1	....	....	....	....	....	....	....	....	....	4
1888	....	1	1	....	....	....	....	....	....	....	....	....	1	3
1889	1	1	3	....	....	....	....	....	....	....	....	....	....	5
1890	5	1	4	....	....	....	....	....	....	....	1	2	....	13
1891	1	4	1	....	....	....	....	....	....	....	....	1	....	7
1892	....	1	....	....	....	....	....	....	....	....	....	1	....	2
1893	....	1	1	....	....	....	....	....	....	....	....	....	....	2
1895	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1896	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1897	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1898	....	....	1	....	....	....	....	....	....	....	....	....	....	1
1899	....	....	....	....	....	....	....	....	....	....	....	1	....	1
1900	1	1	1	1	....	....	....	....	....	....	....	....	....	4
1901	1	....	1	1	....	....	....	....	....	....	....	1	....	4
1902	....	....	....	....	....	....	....	....	....	....	....	1	....	1
1903	2	1	1	1	....	....	....	....	....	....	....	....	....	5
1904	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1905	2	....	1	....	....	....	....	....	....	....	....	....	....	3
1906	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1907	....	....	....	1	....	....	....	....	....	....	....	....	....	1
1908	1	....	2	....	....	....	....	....	....	....	....	....	....	3
1909	....	....	1	1	....	....	....	....	....	....	....	....	....	2
1910	....	....	1	....	....	....	....	....	....	....	....	1	....	2
1911	1	....	....	....	....	....	....	....	....	....	....	1	....	2
1912	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1913	....	1	1	1	....	....	....	....	....	....	....	1	....	4
1914	1	....	2	....	....	....	....	....	....	....	....	1	....	4
1915	1	2	1	1	....	....	....	....	....	....	....	....	....	5
1916	1	1	....	....	....	....	....	1	....	....	....	....	....	3
1917	....	....	1	....	....	1	....	....	....	....	....	2	....	4
1918	....	1	3	....	....	....	....	....	....	....	1	....	....	5
1919	2	2	2	1	....	1	1	....	....	1	....	1	....	11
1920	2	2	2	....	....	....	....	....	....	....	....	....	....	6
1921	2	1	....	....	....	....	....	....	....	1	2	1	....	7
1922	2	2	....	....	....	....	....	....	....	....	....	....	....	5
1923	1	2	4	1	....	....	....	....	....	....	1	....	....	9
Totals	69	48	64	18	2	2	1	1	2	4	8	31	9	259
Per Cent	28	19	25.6	7.2	.08	.08	04	.04	.08	1.6	3.2	12.4		

Table 8 is a record of the regions of origin of cyclones in the South Pacific, according to months and location. This table is an extension of one published by Schück (158), to which has been added the approximate origin of all storms prior to 1922, given in Table 7, and not recorded by Schück. Since information as to the exact place of origin of hardly a single storm is available, this table gives approximate origin only.

In the table figures separated by a dash indicate the relative reliability of data. The figures before the dashes are based on fairly reliable records; those following the dashes on meager information. Thus for the total the place of origin of 157 storms is given with some confidence and the place of origin of 82 storms with doubt.

TABLE 8. REGION OF ORIGIN OF CYCLONES IN THE SOUTH PACIFIC, BY MONTHS AND BY 5° SQUARES

		160-165 E.	165-170 E.	170-175 E.	175-180 E.	180-175 W.	175-170 W.	170-165 W.	165-160 W.	160-155 W.	155-150 W.	150-145 W.	145-140 W.	Total
Jan.	5-10 S.	-1 (?)	.....	.....	1	.....	1	.....	.....	.....	.....	.....	.....	2-1
	10-15 S.	1	.....	.....	1	2	3-7	.....	.....	.....	.....	.....	.....	7-7
	15-20 S.	-1	5-2	1	14-3	-1	4-2	.....	.....	.....	1-1	-2	1	26-12
	20-25 S.	-2	3-1	-1	.....	-1	.....	.....	-1	.....	.....	.....	.....	3-6
	25-30 S.	.....	1	.....	-1	-1	.....	.....	.....	.....	.....	.....	.....	1-2
	30-35 S.	.....	.....	.....	.....	-1	.....	.....	.....	.....	.....	.....	.....	-1
	Total	1-3	9-3	1-1	16-4	2-4	8-9	.....	-1	.....	1-1	-2	1	37-29
Feb.	10-15 S.	.....	.....	.....	.....	.....	1	1	.....	.....	1	.....	.....	3
	15-20 S.	3-1	5	3	7-2	1	2-1	.....	.....	.....	1	.....	.....	22-4
	20-25 S.	1	2	.....	.....	-1	1-1	.....	.....	1	.....	.....	.....	5-2
	25-30 S.	-1	-1	.....	.....	.....	.....	-1	-1	.....	-1	.....	.....	-5
	30-35 S.	.....	.....	.....	-1	.....	.....	.....	.....	.....	.....	.....	.....	-1
	Total	4-2	7-1	3	7-3	1-1	4-2	1-1	-1	1	2-1	.....	.....	30-12
Mar.	10-15 S.	-1	1	-2	1	2	4-1	.....	.....	.....	.....	.....	.....	8-4
	15-20 S.	-3	6	.....	10-3	2	6-2	.....	.....	.....	.....	.....	1-1	25-9
	20-25 S.	5	1-1	.....	-1	-1	-1	.....	.....	.....	.....	.....	.....	6-4
	30-35 S.	-1	.....	.....	.....	.....	.....	.....	.....	.....	-1	.....	.....	-2
	25-30 S.	.....	1	.....	.....	-1	.....	.....	.....	.....	.....	.....	.....	1-1
	Total	5-5	9-1	-2	11-4	4-2	10-4	.....	.....	.....	-1	.....	1-1	40-20
April	10-15 S.	.....	.....	.....	.....	.....	1-1	.....	.....	.....	.....	.....	.....	1-1
	15-20 S.	.....	1	1	5	.....	3	.....	.....	.....	.....	.....	.....	10
	20-25 S.	.....	1	.....	.....	.....	.....	.....	.....	.....	-1	.....	.....	1-1
	25-30 S.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	-1	.....	-1
	30-35 S.	.....	.....	.....	1	-1	2-1	.....	.....	.....	-1	-1	.....	3-4
	Total	.....	2	1	6	-1	6-2	.....	.....	.....	-2	-2	.....	14-7
May	15-20 S.	.....	1	.....	.....	.....	-1	.....	.....	.....	.....	.....	.....	1-1
June	25-30 S.	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2
July	20-25 S.	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
Aug.	25-30 S.	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1

TABLE 8. REGION OF ORIGIN OF CYCLONES IN THE SOUTH PACIFIC, BY MONTHS AND BY 5° SQUARES—CONTINUED

	160-165 E.	165-170 E.	170-175 E.	175-180 E.	180-175 W.	175-170 W.	170-165 W.	165-160 W.	160-155 W.	155-150 W.	150-145 W.	145-140 W.	Total
Sept. 15-20 S.	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	-1	1-1
20-25 S.	.....	.....	-1	.....	.....	.....	.....	.....	.....	.....	.....	.....	-1
Total	.....	1	-1	.....	.....	.....	.....	.....	.....	.....	.....	-1	1-2
Oct. 15-20 S.	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
20-25 S.	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2
25-30 S.	.....	-1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	-1
Total	.....	3-1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3-1
Nov. 10-15 S.	.....	.....	.....	.....	.....	.....	-1	.....	.....	.....	.....	.....	-1
15-20 S.	.....	.....	1	.....	.....	2	.....	.....	.....	.....	.....	.....	3
20-25 S.	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
Total	.....	.....	2	.....	.....	2	-1	.....	.....	.....	.....	.....	4-1
Dec. 10-15 S.	.....	.....	.....	2	1	5	.....	-1	.....	1	.....	.....	9-1
15-20 S.	.....	-1	1	6	-1	2	.....	-1	.....	-1	.....	.....	9-4
20-25 S.	.....	2	.....	-2	.....	-1	.....	.....	.....	.....	.....	.....	2-3
25-30 S.	.....	.....	.....	.....	.....	.....	.....	.....	.....	-1	.....	.....	-1
Total	.....	2-1	1	8-2	1-1	7-1	.....	-2	.....	1-2	.....	.....	19-9
Grand Total	10-11	38-7	8-4	48-13	8-9	37-19	1-2	-4	1	4-7	-4	2-2	157-82

TROPICAL CYCLONES LISTED BY ISLAND GROUPS

The lists of hurricanes in various island groups in the South Pacific (pp. 31-41) include 325 storms, about fifty of which crossed more than one group, and are therefore counted two or three times. Excluding duplications of this sort, the list of recorded hurricanes in the South Pacific, east of the Australian coastal waters, now totals 259.

HURRICANES IN FIJI

The indications are that on the average about two severe cyclonic storms affect Fiji yearly. Usually only a small part of the group is devastated, the remainder experiencing a gale or only a strong wind. Hurricanes severe enough to damage the entire group are rare. The fact that the list of storms in Fiji is larger than any of the other lists does not mean that Fiji has more storms than nearby islands, but rather that there are fewer gaps in the record. As to the monthly distribution, the Fiji list records 25 storms in March, 22 in January, 17 in February, 14 in December, five in April, and one in November.

The following list includes recorded information regarding date, the kind of storm, the area affected and the direction of travel of Fijian hurricanes for the period 1840 to 1923. The numbers in parentheses refer to the bibliography on pages 157-163.

1840, February 22; hurricane: Rewa; also in Cook Islands (28).
1848, January; hurricane.
1848, April 5-6; hurricane (severe): also in Tonga (133).
1856, March; hurricane (severe): north tip of Viti to Tongatabu, southeast (82).
1860, January 28; hurricane.
1864, March 29; hurricane: Lau; Tonga (82).
1866, March 10-12; hurricane (severe): southwest of Vanua Levu (82).
1869, March; hurricane: waves ten feet higher than normal.
1871, March 20; hurricane (severe): entire group; center over West Fiji; to New Hebrides, west.
1873, January 3-7; hurricane: also in New Hebrides (48).
1873, December 30; hurricane: West Vanua Levu, reached New Hebrides January 6th, west (82).
1874, February 15; hurricane: West Vanua Levu (82).
1875, January 7; hurricane: struck Rotuma January 4; recurved in Yasawas; proceeded to Tonga (82).
1875, February 16-20; hurricane (severe): (82).
1875, March 12-13; hurricane (severe): also in Tonga (82).
1875, November 15; hurricane: between Vanua Levu and Samoa; Tonga (204).
1876, January 10; hurricane: (82).
1876, March 16; hurricane: northeast coast of Viti Levu; passed south of Levuka; west-southwest.
1877, March 31; hurricane: entire Tonga; affected Fiji.
1879, December 11-12; hurricane (severe): entire Fiji; severe especially in northwest and west of Viti; Lautoka flooded; Rotumah devastated December 11; southeast.
1880, January 21-26; hurricane (severe): (6).

1881, February 2; cyclone: Vanua Levu and Levuka; center west end of Vanua Levu; east (82).
1881, March; hurricane: west of Viti; southeast (204).
1881, December 31; hurricane: (82).
1882, January; hurricane: southeast of Viti; east-southeast (204).
1883, January 12; hurricane: eastern Fiji; Taviuni; Tonga; southeast (82).
1883, February 24; hurricane: center at Levuka; Taviuni; southeast.
1883, March 12-20; hurricane (severe): (82).
1883, December 27; hurricane: (82).
1884, January 9; cyclone: northwest Vanua Levu; center at Delansau; southwest (82).
1884, February 7; cyclone: recurved east of Delansau; southeast (82).
1886, January; cyclone: west coast of Viti; southeast (204).
1886, March 3-4; hurricane (severe): entire Fiji; severe at Taviuni and Lau; recurved to Ngau; southwest, south, southeast.
1887, March 30; hurricane: (48).
1888, February; hurricane: east central Taviuni, Levuka; southeast (204).
1889, January 23; hurricane: east central Taviuni, Levuka; south-southeast then north-northwest.
1890, February 15; cyclone: Lau (167).
1890, December 24-January 6; hurricane: from Samoa to Taviuni; southwest-south (48).
1891, February 18-19; cyclone: Lau, severe in Ellice Islands and Tonga; southwest, southeast (167).
1892, December; cyclone: north coast of Vanua Levu; over Yasawas; southwest.
1895, January 6-7; hurricane (severe): east coast of Vanua Levu and Viti; center at Levuka; southwest.
1899, December 31; hurricane (severe): recurved in Lau.
1900, February 4; cyclone: Lau (167).
1900, March 12; cyclone: Lau (167).
1901, January 27; cyclone: Lau (167).
1901, March 13-14; hurricane: northeast of Viti, Levuka; recurved 16 degrees south, 177 degrees west; southwest-southeast.
1901, April 2; cyclone: Lau (167).
1901, December 26; cyclone: Rewa.
1902, December 30; cyclone: Levuka; Nausori (204).
1903, January 17; cyclone: Lau; south-southwest.
1903, April 10; cyclone: Taviuni, passed east of Levuka; south-southeast (204).
1904, January 21; hurricane (severe): central Fiji oscillated, northwest and then southeast.
1905, January 6; cyclone: Taviuni and Lau; southwest-south and then southwest.
1905, January 20; cyclone: across Fiji; Lau to Nadi; west-southwest.
1908, January 9; hurricane: east side Vanua Levu and Lau; southeast.
1908, March 23; hurricane: west and south of Viti; southeast.
1909, March 25; hurricane: entire Fiji.
1910, March 24-25; hurricane (severe): Lau and Viti; New Hebrides; Loyalty; and New Zealand; west-southwest.
1911, December 22; hurricane: west Fiji; passed south (107).
1912, January 28-29; hurricane (severe): Entire Fiji; severe west side Vanua Levu; recurved to Tonga.
1913, February 2-9; cyclone: Tonga; affected Fiji (107).
1913, March 17-18; hurricane: southeast of Viti; Taviuni to Suva.
1913, April 16; hurricane: Lau; severe between Tonga and Fiji.
1914, March 13; hurricane: Lau, Levuka and north of Viti; encountered by S. S. "Ventura" 240 miles east of Suva; southwest-southeast (107).
1914, December 24; hurricane: southern Lau; Levuka; northeast of Viti (204).
1915, February 26; cyclone: gale at sea south of Viti (107).
1916, January 9; hurricane: passed 500 miles south of Suva (107).
1917, December 23; gale: New Caledonia on December 18; passed south of Fiji (107).
1919, January 29; gale: passed south of Fiji (107).
1919, February 9; hurricane: Yasawas; southwest (107).

1919, March 28; hurricane: central Fiji; Taviuni then Lau; southwest-southeast (107).
1920, February 24; hurricane: northern Lau; recurved near Wakavo (204).
1920, March 3-4; hurricane: between Fiji and Tonga; south-southeast (153).
1921, February 13; hurricane: Lau; south-southeast (153).
1922, December 17; cyclone: northwest of Fiji.
1923, January 29; cyclone: entire Fiji.
1923, February 13-15; cyclone: entire Fiji.
1923, February 16; cyclone: entire Fiji.
1923, March 15-16; hurricane: Lau.
1923, April 29; cyclone: south of Lau.

HURRICANES IN TONGA

The list of storms in Tonga indicates that on the average, two storms affect that region annually. In some years three occur; in others none. The table records 16 storms in January, 16 in March, seven in February, six in April, four in November, three in December, and one in May. Most of the storms are traveling east, southeast, or south, when they reach Tonga; a few are going west.

....., May; hurricane: (20).
1830, March; hurricane: (52).
1833, January 24; hurricane: Vavau (133, 1845).
1833, March 9; hurricane: Haapai (133, 1845).
1834, ...; hurricane: Haapai; Levuka (52).
1835, November; hurricane (severe): Vavau; Haapai (64).
1837, ...; hurricane; Vavau (142).
1839, February 7-10; hurricane (severe): Haapai; south (133, 1859).
1840, ...; hurricane: Vavau (133, 1850).
1848, April 5-6; hurricane (severe): Tongatabu; Fiji from northeast; south (133, 1859).
1848, April 12-15; hurricane severe): Tongatabu; southeast (133, 1859).
1863, January 10-15; hurricane (severe): Tongatabu; southwest (82).
1864, March 29; hurricane (severe): Tongatabu; Fiji; east (82).
1874, February 12-13; hurricane; Tongatabu; east (6, 1879).
1874, April 10; hurricane: Tongatabu; southwest (6, 1879).
1874, November 13; hurricane (severe): passed just south of Tonga (48).
1875, January 4-9; hurricane (severe): Tongatabu; Fiji; southwest (6, 1877).
1875, March 12-13; hurricane (severe): Tongatabu; Fiji; south (82).
1875, November 16-21; hurricane (severe): Haapai, Keppel Island; south (6, 1877).
1877, March 14-20; hurricane (severe): Tongatabu; Samoa; south (48).
1877, March 31; hurricane: entire Tonga (82 and 204).
1877, December 19; hurricane: Tongatabu; southwest (48).
1879, March 3-9; hurricane (severe): Tongatabu; Vavau; Samoa; west (6, 1879) (48).
1879, March 15; hurricane: Vavau; east (48).
1882, February 2; hurricane: east of Tonga (48).
1882, March 25; hurricane (severe): Vavau; Hifo; southeast (6, 1882).
1883, January 1; hurricane: north of Tonga (48).
1883, January 12; hurricane (severe): Tongatabu (82, 1883).
1887, January 5; hurricane: south of Tonga (48).
1888, March 19-20; hurricane: Vavau; south.
1888, ...; hurricane: Tongatabu (20).
1890, January 21-22; hurricane: south of Tonga.
1891, January 26; hurricane: Tongatabu; west (184).
1891, February 19; hurricane: Tongatabu; Fiji; southeast (183).
1896, January 3; hurricane: Haapai (183).

1900, January 2; hurricane: (37).
1900, April 12; hurricane: from northwest (140).
1901, January 27; hurricane: east of Tonga (37).
1903, February 14; hurricane: Nukualofa (37).
1908, March 24; cyclone: south of Nukualofa; east (37).
1909, April 13; hurricane: Niuafou (183).
1910, December 31; cyclone: Niuafou; east (37).
1911, January 5; cyclone: Niuafou from west, south of Nukualofa (37).
1912, January 30; hurricane: entire Tonga from Fiji (183).
1913, February 9; hurricane: entire Tonga (183).
1913, April 16; hurricane (severe): between Fiji and Tonga (63).
1913, December 28; cyclone: Niuafou; center passed eastward north of Niuafou (37).
1914, March 25; hurricane: moved eastward north of Nukualofa; severe in Vavau (37).
1915, January 16-18; cyclone: Tongatabu (37).
1915, March 20; hurricane: severe in Vavau (37).
1916, January 9; hurricane: passed southward as gale (37).
1916, February 10; cyclone: west of Tonga (107).
1918, March 1; hurricane: Niuafou (41).
1920, January 15-18; cyclone: east of Lau (167).
1920, March 3; hurricane: between Fiji and Tonga.
1923, March 6; hurricane: from Samoa to Tonga (187).
1923, March 16; hurricane: Haapai (187).
1923, November 28-29; hurricane: entire Tonga (187).

HURRICANES IN SAMOA

The list for Samoa shows that during the period for which full information is available, an average of two or three hurricanes occurred annually. The list includes 10 storms in January, nine in March, six in December, two each in April and February, and one in November. Most of the storms appear to come from a northerly direction, although some come from the east.

1831, December 20-24; hurricane: Savaii; Cook Islands.
1836, ...; hurricane: Apia; Upolu (64).
1839, ...; hurricane: Upolu (52).
1840, December 16-17; hurricane: Apia; Tutuila; north (52).
1842, December 15-18; hurricane: Samoa; Cook Islands (52).
1846, March 16-17; hurricane: Apia; Cook Islands (52).
1848, December 24; hurricane: Apia to Cook Islands (52).
1850, April 4-7; hurricane: Apia; Tutuila; southeast (52).
1863, January 10-15; hurricane: Apia; southwest (82).
1865, January 25-February 3; hurricane: Savaii; Apia to Raratonga; northwest (82).
1869, January 12; hurricane: Apia; southwest (48).
1869, January 31; hurricane: Apia; north (48).
1869, March 6-7; hurricane: Apia; west (48).
1869, March 16-17; hurricane: Apia; southwest (48).
1870, January; hurricane: Upolu devastated (20).
1875, December 24; hurricane: between Samoa and Tahiti (48).
1877, January 22; hurricane: Apia; southwest (48).
1877, March 14-20; hurricane (severe): Apia; Tonga; west (48).
1877, April 3; hurricane: Apia; southwest (48).
1879, March 3-8; hurricane (severe): Apia; Tonga; north (6).
1883, March 24-25; hurricane: Apia (6).
1885, January 13; hurricane: southwest from Samoa (48).
1886, January 7; hurricane: Upolu (48).

1889, February 9-18; hurricane: Wallis Island; northwest (6).
1889, March 7-8; hurricane: (6).
1889, March 14-23; hurricane (severe): Apia (6).
1890, January 13; hurricane: Upolu.
1890, November 18; hurricane: Upolu (48).
1890-91, December 24-January 6; hurricane: Rohilla; Fiji; northwest and west-southwest (48).
1910, March 22; hurricane (severe): west of Samoa to Fiji (41).
1915, January 18; hurricane (severe): east (140).
1915, February 12; hurricane (severe): American Samoa (140).
1923, March 6-8; hurricane: nearby (187).
1923, November 28-29; hurricane.

HURRICANES IN THE NEW HEBRIDES

From New Hebrides for the 26 years, 1867-1893, 22 hurricanes are reported. There is a period of eight years with no record, and information for other years is lacking. As many as three hurricanes have occurred in one year. On the other hand, three or more consecutive years have passed during which no hurricane was reported. The average storminess may be two hurricanes a year. As to monthly distribution, nearly all the recorded storms have occurred in the first three months of the year, 12 in January, 11 in February, and nine in March. However, two storms occurred in April, two in November, one in May, and one in October.

1847, January 16; hurricane: entire Tanna (133, 1863).
1847, March 2-11; hurricane: southern New Hebrides (52).
1848, February 1-15; hurricane (severe): Erromango and Tanna; New Caledonia; southwest (52, 1848).
1848, December 25; hurricane: near New Hebrides (52).
1852, February 18-24; hurricane (severe): Aneityum (52).
1854, January 1; hurricane: east (167).
1860, March 14; hurricane: west of New Hebrides.
1862, January 17-18; hurricane: east-southeast of Tanna (133, 1863).
1867, February 27; hurricane: west of New Hebrides (160).
1867, March 7; hurricane: Futuna and Efate (140).
1868, January 30; hurricane: (140).
1868, April 21; hurricane: (140).
1868, May 17; hurricane: (140).
1869, February 23; hurricane: (140).
1871, March 17-22; hurricane: Futuna; Fiji (140).
1872, February 17; hurricane: Futuna and elsewhere (140).
1873, January 3-7; hurricane (severe): New Hebrides; Fiji (48).
1874, February 15-25; hurricane (severe): New Hebrides; New Caledonia; north (6, 1879).
1874, October 2; hurricane: (140).
1878, January 9; hurricane: Sandwich Island.
1879, January 9-10; hurricane: (153).
1880, January 21-26; hurricane (severe): New Hebrides; New Caledonia (6, 1880).
1889, March 16; hurricane: west of New Hebrides (82).
1890, January 2; hurricane: passed between New Hebrides; New Caledonia (48).
1891, February 10-11; hurricane: crossed southern New Hebrides; northeast (48).
1891, March 9-12; hurricane: New Hebrides; Solomon Islands (140).
1892, February 14-18; hurricane: did considerable damage (140).

1893, February 17; hurricane (severe): storm moved west over Fortuna (140).
1893, March 5; hurricane: Api and elsewhere (140).
1903, March 3-6; hurricane: west from Espiritu Santo (140).
1907, April 11; hurricane: very severe near Fortuna (41).
1910, March 25; hurricane: crossed New Hebrides coming from Fiji (41).
1916, January 8-9; hurricane (severe): western New Hebrides, then to New Caledonia (41).
1918, November 11; hurricane (severe): Tonga region (41).
1921, November 23; cyclone: Sugar Ville, Canal Segond; southeast (41).
1922, February 3; hurricane: general (63).
1922, February 25-26; hurricane: general (63).
1922, December 17; hurricane: general.
1923, February 13-14; hurricane.

HURRICANES IN NEW CALEDONIA

Judging from recent years, for which fairly full information has been gathered by me, an average of about three severe tropical cyclones affect some part of New Caledonia annually. As to monthly distribution, of the 44 storms listed from New Caledonia, 13 occurred in February, 10 in March, 10 in January, five in December, two in October, and one each in July and September. Most of the storms affecting this area move southeastward, although a number are traveling southwestward and others southward.

1830, ...; hurricane: especially Loyalty Islands (52).
1847, March 2-11; hurricane: extending southeast (52).
1848, February 10-15; hurricane (severe): Lifu; Loyalty Islands; New Hebrides; extending southwest (52).
1849, February 12-15; hurricane; Huon (52).
185.., September 26; hurricane: Lifu; Loyalty Islands.
1852, February 18-24; hurricane: Aneitum; extending north (52).
1854, January 1; hurricane.
1874, February 15-25; hurricane: New Caledonia; New Hebrides; from north (82).
1876, February 23-24; hurricane: Numea, Pam (northern part of island) (6, 1876).
1878, January 31; hurricane: Lifu; Noumea (6, 1878).
1880, January 21-26; hurricane (severe): Noumea; also New Hebrides; from northwest (6, 1880).
1880, February 3-11; hurricane: Noumea, from the north (6, 1880).
1880, March 8-10; hurricane: (6, 1880).
1887, January 6; hurricane: (48).
1890, January 2; hurricane: passed between New Hebrides and New Caledonia (48).
1890, March; hurricane (severe): northern New Caledonia.
1891, February 1; hurricane: south of New Caledonia (48).
1891, February 10-11; hurricane: from the northeast (48).
1898, March 28-31; hurricane: south of New Caledonia.
1910, March 25-28; hurricane (severe): from Fiji, went to Norfolk (41).
1916, January 9; hurricane: (41).
1917, March 28-31; hurricane: from the north (41).
1917, December 1-5; hurricane; from the west (41).
1917, December 18; hurricane: moved east (41).
1918, February 12-14; hurricane: moved south (41).
1918, March 16-20; hurricane: near New Caledonia (41).
1918, March 25-28; hurricane: near New Caledonia (41).
1919, January 12-15; gales: from the northeast (41).
1919, January 25-30; gales; from the northeast (41).
1919, February 10; hurricane moved south (41).

1919, March 15-19; gales: from the northwest (41).
1919, April 14-16; gales: from the northeast; Norfolk (41).
1919, July 28; hurricane: between New Caledonia and Queensland (41).
1919, October 28-30; gales: from the northwest (41).
1919, December 29-30; gales: from the northeast (41).
1920, February 11-14; hurricane: from the north (41).
1920, March 15-18; hurricane (41).
1921, January 31; hurricane: south of New Caledonia from the west (41).
1921, October 2-6; hurricane: from the north, between Queensland and New Caledonia (41).
1921, December 11; Noumea (41).
1922, January 19-21; cyclone: northern New Caledonia; Norfolk Island, from north (41).
1922, December 17; hurricane (41).
1923, February 13-16; hurricane: New Caledonia; Norfolk Island from north (41).
1923, February 15-17; hurricane: closely followed preceding storm (186).

HURRICANES IN NORFOLK ISLAND

For eight years, 1915-1922, the records show that there was an average of more than one hurricane a year in or near Norfolk Island. February, with nine hurricanes, appears to be the most stormy month; March has seven, January four, April, June and October two each, and August and December one each.

1789, February 26; hurricane (severe): from northeast (52).
1846, March 10; hurricane: from west (52).
1847, March 2-11; hurricane.
1847, October 5-6; hurricane: from southwest.
1848, February 10-15; hurricane: Port St. Vincent from southwest (52).
1852, February 18-24; hurricane: from north (52).
1852, March 5-6; hurricane (severe): from southwest (52).
1859, February 21; hurricane: east and south of Norfolk.
1879, January 2-12; hurricane: (153).
1891, February 1; hurricane: west of Norfolk (48).
1910, March 29; hurricane (severe): from Fiji, New Caledona to New Zealand (205).
1915, April 26-28; hurricane: from southeast (41).
1916, August 2; (41).
1917, March 28-31; hurricane: from north (41).
1917, June 23; hurricane (severe): from west (41).
1918, March 18; hurricane (severe): (41).
1919, February 14; hurricane: from Queensland coast (41).
1919, April 19; cyclone: east-southeast (41).
1919, June 2; cyclone: east-southeast (41).
1919, October 29-30; cyclone: east-southeast (41).
1920, January 24; cyclone: east-southeast (41).
1920, February 11-14; hurricane: from New Caledonia (41).
1920, March 23-27; hurricane: (41).
1921, January 13; cyclone: hurricane passed just east; south-southeast (41).
1922, January 19-21; hurricane (severe): affected entire group, also Fiji (63).
1922, December 17; hurricane: general, from north (186).
1923, February 16-17; hurricane: general from north (186).
1923, February 14-15; hurricane: general, from north (186).

HURRICANES IN AND NEAR COOK ISLANDS

The list for the Cook Islands is obviously incomplete. Judging from two decades, a hurricane occurs in or near the region, on the average,

about every two years, although very severe storms are rare. The list includes five storms each in December and February, three in March, and two each in January and April. Apparently most of the storms move southeastward.

1831, December 21; hurricane: Raratonga; Samoa (52).
1839, February 7-10; hurricane: Cook Islands; south (133, 1859).
1840, February 22-March 1; hurricane: Cook Islands; Fiji; south (52).
1842, December 15-18; hurricane: Mangaia; Samoa; northeast (52).
1845, January 16-17; hurricane: Cook Islands (52).
1846, March 16-18; hurricane: Raratonga and Mangaia; Fiji; southwest (52).
1848, December 24; hurricane: Hervey Island, from Samoa (52).
1865, January 25-February 3; hurricane: Cook Islands, from Samoa; northwest.
1869, April 4-5; hurricane: south of Austral Islands (48).
1877, February 24; hurricane: east of Cook Islands (6, 1878).
1882, February 2; hurricane: southwest of Austral Islands (48).
1882, March 18; hurricane: at Austral Islands (48).
1883, December; hurricane: severe at Palmerston Island (20).
1887, April 10-11; hurricane: south of Austral Islands (48).
1889, February 18; hurricane: Raratonga, from Wallis Island; Samoa (6, 1892).
1890, December 15; hurricane: south of Austral Islands (48).
1897, February 10-11; hurricane: Raratonga.
1923, March 8; hurricane: north of Kermadec Islands (186).

HURRICANES IN THE SOCIETY ISLANDS

According to available records, hurricanes are rare in the Society Islands, occurring on the average each three to five years. However, two are recorded in one year. The list for this group shows that December and January have three each and that one each is recorded for September and February.

1819, ...; hurricane.
1838, ...; hurricane.
1843, December 19; hurricane (severe): (52).
1848, December 24; hurricane: (52).
1856, January 21; hurricane: (133, 1856).
1861, December; hurricane: (140).
1877, January 18-19; hurricane: between Tuamotus and Society Islands (48).
1877, September; hurricane (severe): Anaa and Kaukura (6, 1879).
1903, January 13-15; hurricane: (140).
1906, February; hurricane: entire Tuamotu Group devastated (140).

HURRICANES IN THE TUAMOTUS

Four severe hurricanes in one four-year period and three in another four-year period constitute the record for the Tuamotus. For decades without recorded storms, information is probably inadequate. The short list includes three storms in January, two in February, and one each in March and September.

1875, January 4-9; hurricane: (6, 1877).
1877, January 18-19; hurricane: between Tuamotus and Society Islands (48).
1877, September; hurricane (severe): Manihi, Kaukora, Fakarava, Anaa and Nihiru Islands (140).

1878, February 5-8; hurricane (severe): General Manihi, Kaukora, Fakarava, Anaa and Nihiru Islands; moved east (140).
1903, January 13-15; hurricane (severe): Tuamotu Islands.
1905, March 12; hurricane: (140).
1906, February (140).

HURRICANES IN THE SOLOMON, ELLICE AND TOKELAU ISLANDS

It is worthy of note that the hurricanes listed for the Solomon, Ellice, and Tokelau islands occurred within ten degrees of the Equator, where few such storms are to be expected. Of the six storms recorded, one occurred in December, two in January, one in February, and one in March.

1840, December; hurricane: west of Solomons, near east coast of New Guinea (52).
1880, January 20; hurricane: near Savo (63, 1880).
1890, March 3; hurricane: southern end of the Solomon Islands (48).
1891, March 4-12; hurricane: Santa Cruz Islands, east of Solomon Islands, then to New Hebrides (41).
1891, February 18; hurricane (severe): entire Ellice Islands devastated (140).
1914, January 7; hurricane: Atufu, Tokelau Islands devastated (140).

TYPHOONS IN THE WESTERN NORTH PACIFIC

Tropical cyclones, there usually called typhoons, are very numerous in the Western North Pacific, the "Far East," and many of them are terribly destructive. In this region typhoons appear to be somewhat more severe, on the average, than are the tropical cyclones of any other part of the Pacific, but the resulting high mortality is particularly due to the large population living along low lying coasts or in valleys subject to sudden floods. Even far from shore, the typhoons do much damage, for boats are very numerous in the Western North Pacific, and many of the smaller ones, especially the fishing boats, are ill-adapted to withstand a hurricane.

The frequency and destructiveness of typhoons and the fact that there are several scientific observatories in or bordering the Western North Pacific, as well as many scientific visitors, have combined to encourage the study of typhoons. Three comprehensive monographs have appeared, (1, 51, 65), and many shorter papers (48, 66, 158, 93, 38, 194). Each recent issue of the Monthly Weather Review contains notes by Coronas on Philippine Storms.

ANNUAL FREQUENCY

As to the annual frequency of typhoons there is considerable difference of opinion, for a storm which by one observer is described as a true typhoon, by another may not be considered severe enough to be so classed. Furthermore, although each observatory attempts to cover almost the entire region, there is in fact a certain amount of specialization. This is frankly recognized by Coronas (38), who attempts to list only those typhoons which have noticeably affected the weather of the Philippines. However, several lists of typhoons purport to be complete for the entire western North Pacific—the "Far East"—but the annual number of typhoons reported by different observers varies greatly. The discrepancy is shown in Table 9, which lists typhoons recorded during certain years by Algué (1, p. 86), Froc (66, pp. 202-239), the Deutsche Seewarte (48, p. 256), and by the Director of the Royal Observatory at Hongkong, who supplied me with an unpublished list.

Notwithstanding the use of the radio, differences of opinion in classifying as typhoons has not ceased to exist. For example, in 1918, Claxton reported 19 typhoons, Froc reported 16, and Okada (then at the Central Meteorological Observatory, Tokyo) reported 14 severe typhoons and 9 other tropical cyclones. Table 9 shows that some supposedly complete lists contain only a third or even a fourth as many storms as are recorded

in other authoritative lists for the same year. Hence, any list may be criticized as incomplete or as including storms that should not be called typhoons. However, it is very desirable, particularly for the study of climatic cycles, to have as complete a list as possible. With this in view, Table 10 has been prepared. It is made up from three sources: for the years 1893 to 1918, inclusive, the list has been compiled from Froc's itemized list of 617 typhoons (65)—the longest available list compiled by a single observer. For the years 1880 to 1892, Algué's list is reprinted. Algué informed me that no comprehensive list has been compiled at the Philippine Weather Bureau since 1904. For the years 1919 and 1920, the list supplied by Director Claxton of the Royal Observatory, Hongkong, was used, as Froc has not yet compiled his lists for those years. A very incomplete list for the century before 1880 is given in the Segelhandbuch (48). Because of their incompleteness, however, no very safe deductions as to averages or cycles of occurrence can be based on these early records.

TABLE 9. NUMBER OF TYPHOONS AS RECORDED BY DIFFERENT OBSERVERS

	Algue'	Froc	Hongkong Observatory	Deutsche Seewarte
1884	21	....	19	19
1885	11	....	10	10
1886	16	....	14	12
1887	28	....	26	24
1888	16	....	14	6
1889	14	....	12	7
1890	27	....	16	4
1891	28	....	16	6
1892	24	....	19	....
1893	24	11	16	....
1894	34	31	16	....
1895	24	19	12	....
1896	20	13	20	....
1897	20	14	11	....
1898	25	22	21	....
1899	21	22	19	....
1900	23	23	13	....
1901	27	21	9	....

Table 10 shows that, on the average, about twenty-three severe tropical cyclones occur annually in the "Far East." Froc's list for 1893-1918 averages 24 a year. The annual variation is great, however, according to these data from 11 to 38. In a smaller region it is, of course, still greater. For example: in the Philippines the number of especially severe ("remarkable") typhoons varied during the years 1903-918 from one in 1916 to seven in 1911. Of all the typhoons occurring in the Western North Pacific in an average year, perhaps half have winds of hurricane force

over a wide and long belt. The others have winds of hurricane force in only a small area; many have only the force of gales.

TABLE 10. TYPHOONS OF THE WESTERN NORTH PACIFIC, 1880-1920, BY YEARS AND MONTHS

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Total
1880	....	....	....	....	....	....	2	4	2	2	1	....	11
1881	....	....	....	....	2	1	3	4	4	3	3	1	21
1882	....	....	....	1	....	..	3	....	2	2	1	2	11
1883	....	....	1	1	3	1	3	4	4	4	1	....	22
1884	1	....	....	....	2	1	4	5	4	....	2	2	21
1885	....	....	....	1	....	2	2	2	1	1	1	1	11
1886	....	....	....	1	1	2	....	3	4	3	1	1	16
1887	....	....	1	3	3	1	5	2	7	3	3	....	28
1888	....	....	....	1	....	2	4	3	3	1	1	1	16
1889	....	....	....	....	....	....	2	3	2	4	1	2	14
1890	1	....	....	....	1	5	4	2	7	6	1	....	27
1891	....	....	....	1	2	2	7	5	6	....	4	1	28
1892	1	....	....	....	....	3	4	4	5	2	3	2	24
1893	....	....	....	....	1	....	3	2	2	3	....	....	11
1894	....	....	....	1	4	3	7	2	4	4	4	2	31
1895	....	....	....	....	1	4	4	3	4	3	....	....	19
1896	....	....	....	....	1	2	4	2	1	3	....	....	13
1897	....	....	1	....	....	..	4	1	3	4	1	....	14
1898	....	....	1	1	....	..	3	4	4	4	4	1	22
1899	1	2	....	....	2	1	2	4	4	3	3	....	22
1900	2	....	1	....	....	1	1	4	4	4	4	2	23
1901	2	1	....	1	2	2	1	3	2	5	1	1	21
1902	1	....	....	....	3	3	4	2	5	3	1	2	24
1903	3	1	1	1	1	1	3	4	6	6	2	2	31
1904	....	....	2	1	....	2	5	4	3	2	1	3	23
1905	1	....	2	1	1	2	3	4	3	4	1	2	24
1906	1	4	1	....	3	....	2	1	8	3	1	....	24
1907	3	3	1	1	1	2	3	6	4	4	4	....	32
1908	1	1	2	2	3	1	3	4	4	4	3	3	31
1909	5	....	1	1	2	1	4	3	6	6	2	4	35
1910	2	1	2	1	4	2	3	5	10	2	3	3	38
1911	1	2	....	1	1	2	7	6	3	4	2	1	30
1912	4	1	....	....	....	....	3	5	4	4	4	2	27
1913	1	....	....	....	1	....	5	4	5	5	1	1	23
1914	....	....	1	....	1	3	4	6	4	2	2	2	25
1915	....	....	1	....	....	..	3	3	3	7	4	2	23
1916	3	1	....	1	1	1	2	3	6	1	3	1	23
1917	....	....	1	....	....	....	3	5	4	2	1	....	16
1918	....	....	....	1	....	1	4	4	3	3	....	....	16
1919	2	....	1	....	....	1	5	6	4	4	2	1	26
1920	1	....	....	1	....	1	3	6	4	2	2	....	20
Total	37	17	21	24	47	56	141	147	168	132	79	48	917
Percentage	4.0	1.8	2.3	2.6	5.1	6.1	15.4	16.0	18.3	14.4	8.6	5.2	99.8

SEASONAL OCCURRENCE

The month of occurrence of 917 "Far East" typhoons is shown in Table 10, which also gives the number and the percentage of the total for

each month. The same data is presented graphically in figure 8. The table and figures show that, although occurring in considerable numbers in every month of the year, tropical cyclones are most frequent in the western North Pacific in the four months, July, August, September, and October. The great abundance of storms in July and August has usually been explained by the fact that in those months the doldrums are farthest from the Equator. This relationship appears to be the most important single one, but other influences have some effect, for by October, or at least by November, the doldrums are far south of their position in June, a month of relatively few typhoons. Furthermore, typhoons are rarest in February and March, not in January, the coolest month; the monthly variation in the temperature of the surface of the ocean appears to be a factor influencing the development of cyclones. The ocean normally is cooler in February than in January. Other causes are discussed on pages 86-87.

Table 11, based on Coronas (38, pp. 181-185) shows the monthly distribution of cyclones in the Philippines during the years 1903-1918. The figures give percentages.

TABLE 11. AVERAGE MONTHLY DISTRIBUTION OF TYPHOONS IN THE PHILIPPINES, 1903-1918

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Storms a Year
emarkable Typhoons	1.7	....	....	1.7	5	6.7	10	15	21.7	21.7	10	6.7	4
rdinary Typhoons....	4.9	....	4.9	4.9	9.8	3.3	9.8	3.3	13.1	13.1	24.6	8.2	5
Average.....	3.3	....	2.4	3.3	7.4	5.0	9.9	9.2	17.4	17.4	17.4	8	....

The monthly distribution of the storms in latitudes 5° to 8°, merits special attention for tropical cyclones are relatively rare so near the Equator. Table 12, which is based on Table 21, gives the number and the per cent in each month.

TABLE 12. MONTHLY DISTRIBUTION OF 70 TYPHOONS IN LATITUDES 5-8 N.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Number	4	2	4	1	6	6	5	4	4	9	9	16
Per Cent.....	5.1	2.9	5.7	1.4	8.6	8.6	7.1	5.7	5.7	12.9	12.9	22.8

The monthly distribution of these subequatorial typhoons may be contrasted with that of typhoons in general (fig. 8). The months of both maximum and minimum frequency are later in the year near the Equator than in the latitudes farther north. The maximum is in December instead of in September, and the minimum in April rather than in February or March. Another contrast is that, near the Equator, May and June have

more typhoons than August and September, while the reverse is true above latitude 10 degrees. The latitudinal contrasts in the monthly distribution are at least largely due to variations in the extent and effect of the Asiatic high pressure area rather than solely to the systematic shifting of the doldrums, the common explanation. As Taylor (178, p. 280) has shown, the heat Equator is in the Southern Hemisphere in these general longitudes during nearly half the year.

LATITUDE AND LONGITUDE OF ORIGIN

Thirty-five years ago Doberck (51) expressed the view that many typhoons originated in the China Sea. But soon after the Philippine Weather Bureau was organized it was discovered that nearly all China Sea typhoons originated to the east of the Philippines. Algué pointed this out in 1904. With the establishment of reporting stations at Guam and Yap, the place of origin of many storms was found to lie to the east of these islands. Today, although it is known that most typhoons first attain destructive violence west of longitude 150° E., the recently established Japanese Meteorological Observatory at Jaluit (longitude 170° E., latitude 6° N.) reports that frequently cyclonic disturbances pass the Marshall Islands on their way westward. Such observations make more plausible the suggestion of Kimball (105, p. 486) that some of the tropical cyclones which develop off the west coast of Mexico and Central America may cross the Pacific. Mitchell (126) reports that many hurricanes have been traced westward most of the distance across the Atlantic, from near the Cape Verde Islands to the West Indies.

Algué, Froc and Okada expressed to me the belief that some typhoons develop far out in the Pacific. Of the storms which originate fairly near reporting stations, there is considerable seasonal variation in latitude and longitude of place of origin. In brief, most winter storms originate either farther south or farther north than the storms of the main typhoon season. With respect to longitude, the data suggest that the winter and spring storms normally originate somewhat west of the average longitude of summer and autumn storms (fig. 9). Froc (65, chart 21) believes that the longitude of origin is progressively farther eastward month by month from October to January. For the area of origin and courses followed by typhoons, see figure 9 and pages 55 and 66.

CYCLONES IN THE EASTERN NORTH PACIFIC

Redfield (150) presents a chart showing the approximate tracks of 13 cyclones, most of them in the region just west of Mexico, but some near Hawaii. The Deutsche Seewarte (48) publishes a list of 45 storms occurring in that region between 1832 and 1892; no mention being made, however, of those described by Redfield. The courses of 6 were traced by Hurd (93). Severe storms occurring in September, 1915, and September, 1918, are described by Kimball (105) and Tingley (180) and brief mention is made by Tingley (181) of 4 storms occurring in 1921 and 1922. Data regarding these seventy storms were published by me in 1922 (192) and the tracks of about sixty were reprinted from various sources.

Soon afterwards Hurd (96) compiled data concerning 27 additional storms, most of them occurring in the years 1912 to 1923. Table 13 lists these storms and gives data concerning them. Their monthly distribution is shown in detail in Table 14 and summarized in Table 16. (See also fig. 8.) It will be noted that all but five of them occurred in the six months' period, June to November, inclusive. September with 33 per cent is the stormiest month, and October with 23 per cent is next. Nearly 80 per cent of the storms are recorded for the four months July to October, inclusive.

The approximate place of origin of 79 storms in the Eastern North Pacific is shown in Table 16, which is a revision of one published previously by me (191) and incorporates data concerning 11 additional storms, made available by Hurd (95).

Cyclones off the west coast of Mexico and Central America are not discussed in standard treatises or included in recent lists of tropical cyclones (135) but they should not be ignored. Table 16 suggests that two or more tropical cyclones occur on the average each year in this region. Twenty-six are recorded for the 11 year period, 1849 to 1859; 24 for the 13 year period, 1880 to 1892; and 29 for the 11 year period, 1912 to 1922. The 97 storms listed in Table 14 were recorded in just half that many years. For 1855, 7 were recorded; for 1922, 6; probably storms occurred during the year for which no published record exists. Searching the reports of ship officers for the years 1911-1921 has added 18 storms to my published list (191).

The recorded storms of the Eastern North Pacific have been far less destructive than have those of the West Indies and of the China Sea, largely, however, because this region has heretofore been little used by shipping. With increased use of the Panama Canal route a fuller knowledge of these storms is desirable.

TABLE 13. LIST OF TROPICAL CYCLONES IN THE EASTERN NORTH PACIFIC.

(The figures in parentheses refer to Bibliography, page 157.)

Year Month	Place of Origin or First Record
1832 Dec.	13 N., 148 W. (48)
1839 Nov. 1	23 N., 106 W. (48)
1840 Nov. 1	22 N., 105 W. (48)
1842 Oct.	15 N., 95 W. (48)
1843 Sept. 23	15 N., 139 W. (151)
1847 Oct. 24	17 N., 106 W. (151)
1849 June 21-22	16 N., 116 W. (151)
1850 June 24	16 N., 107 W. (151)
1850 Aug. 5	14 N., 117 W. (151)
1850 Sept. 9-11	15 N., 100 W. (151)
1850 Sept. 26	26 N., 123 W. (151)
1850 Oct. 1-6	18 N., 104 W. (151)
1850 Oct. 3	14 N., 117 W. (151)
1850 Oct.	17 N., 105 W. (48)
1851 Sept. 16	15 N., 120 W. (48)
1851 Oct.	21 N., 107 W. (48)
1851 Oct. 21	22 N., 110 W. (151)
1852 July 16-19	15 N., 115 W. (48)
1854 Oct. 5	28 N., 135 W. (48)
1855 June	20 N., 105 W. (151)
1855 Aug. 3-6	18 N., 109 W. (48)
1855 Aug. 8-9	15 N., 117 W. (151)
1855 Sept. 4	20 N., 122 W. (151)
1857 June 20	11 N., 110 W. (48)
1857 Sept. 6	19 N., 121 W. (48)
1858 Aug. 17	13 N., 115 W. (48)
1858 Nov. 21	21 N., 174 W. (48)
1859 Sept. 10	16 N., 99 W. (48)
1865 July 25	10 N., 109 W. (48)
1870 June 17	16 N., 106 W. (48)
1870 Sept. 21-24	17 N., 141 W. (48)
1871 July 3	16 N., 117 W. (48)
1874 Nov. 19	16 N., 161 W. (48)
1877 Nov. 5	14 N., 123 W. (48)
1880 July 6	20 N., 120 W. (48)
1880 Oct. 13	18 N., 111 W. (48)
1882 July 31	13 N., 118 W. (48)
1882 Sept. 7	14 N., 105 W. (48)
1882 Sept. 21-23	20 N., 105 W. (48)
1883 Oct. 3	23 N., 106 W. (48)
1884 Sept. 28-30	17 N., 107 W. (48)
1884 Oct. 23	24 N., 107 W. (48)
1885 July 31	20 N., 130 W. (48)
1885 Sept. 12	23 N., 128 W. (48)
1885 Oct. 5-6	24 N., 108 W. (48)
1885 Oct. 25	21 N., 106 W. (48)
1886 Sept. 19	16 N., 95 W. (48)
1887 July 6	20 N., 114 W. (48)
1887 Oct. 3-6	17 N., 107 W. (48)
1888 Aug. 9-10	15 N., 120 W. (48)
1888 Aug. 13-14	12 N., 120 W. (48)
1888 Sept. 10-11	17 N., 106 W. (48)
1888 Sept. 20	23 N., 107 W. (48)
1889 Aug. 2-3	14 N., 122 W. (48)
1890 Aug. 18-19	16 N., 124 W. (48)
1891 Aug. 2	16 N., 118 W. (48)
1891 Aug. 7	11 N., 107 W. (48)
1892 July 19	20 N., 117 W. (48)
1895 Sept. 29-Oct. 1	9 N., 112 W. (96)
1899 Aug. 27-31	14 N., 112 W. (96)
1899 Sept. 3-5	23 N., 113 W. (96)
1902 Dec. 23-Jan. 2	21 N., 158 W. (93)
1904 Nov. 26-Dec. 4	18 N., 161 W. (93)
1904 Dec. 23-30	15 N., 156 W. (93)
1906 May 3-10	12 N., 152 W. (93)
1906 Oct. 2-9	18 N., 154 W. (93)
1906 Nov. 6-13	20 N., 157 W. (93)
1912 Aug. 10-11	17 N., 116 W. (96)
1912 Sept. 19-20	19 N., 116 W. (96)
1912 Sept. 28	18 N., 105 W. (96)
1912 Oct. 30	14 N., 100 W. (96)
1913 Aug. 24	17 N., 121 W. (96)
1915 July 4-6	10 N., 90 W. (96)
1915 Sept. 4	14 N., 108 W. (129, Vol. (43-480)
1915 Sept. 19-22	12 N., 100 W. (96)
1915 Oct. 8-9	13 N., 98 W. (96)
1917 Sept. 16-17	20 N., 105 W. (96)
1917 Sept. 27-28	13 N., 105 W. (96)
1917 Oct. 12	22 N., 105 W. (96)
1918 Sept. 10-11	22 N., 110 W. (96)
1918 Sept. 13-17	14 N., 103 W. (129)
1919 Sept. 24	20 N., 108 W. (96)
1919 Oct. 30	15 N., 96 W. (96)
1920 Sept. 9-13	14 N., 103 W. (96)
1921 Mar. 16-17	21 N., 87 W. (129)
1921 Sept. 17	20 N., 108 W.
1921 Sept. 24-30	16 N., 104 W. (129, vol. 49, p. 518)
1921 Oct. 4	22 N., 156 W. (129, vol. 49, p. 579)
1921 Oct. 9	14 N., 94 W. (129, vol. 49, p. 581)
1922 Feb. 2	15 N., 94 W. (129, vol. 50, p. 99)
1922 July 31	14 N., 118 W. (96)
1922 Aug. 27-30	14 N., 97 W. (96)
1922 Sept. 1	16 N., 102 W. (96)
1922 Sept. 9-10	16 N., 112 W. (96)
1922 Oct. 15	21 N., 110 W. (96)
1923 Jan. 13-16	21 N., 155 W. (129, vol. 51, p. 36)
1923 Mar. 20	14 N., 96 W. (129, vol. 51, p. 150)

TABLE 14. TROPICAL CYCLONES OF THE EASTERN NORTH PACIFIC BY YEARS AND MONTHS (THE RECORD FOR 1923 IS INCOMPLETE)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1832	....	....	....	....	....	....	....	....	....	....	....	1	1
1839	....	....	....	....	....	....	....	....	....	....	1	....	1
1840	....	....	....	....	....	....	....	....	....	....	1	....	1
1842	....	....	....	....	....	....	....	....	....	1	....	....	1
1843	....	....	....	....	....	....	....	....	1	....	....	....	1
1847	....	....	....	....	....	....	....	....	....	1	....	....	1
1849	....	....	....	....	....	1	....	....	....	....	....	....	1
1850	....	....	....	....	....	1	....	1	2	3	....	....	7
1851	....	....	....	....	....	....	....	....	1	2	....	....	3
1852	....	....	....	....	....	....	1	....	....	....	....	....	1
1854	....	....	....	....	....	....	....	....	....	1	....	....	1
1855	....	....	....	....	....	1	....	2	1	....	....	....	4
1857	....	....	....	....	....	1	....	....	1	....	....	....	2
1858	....	....	....	....	....	....	....	1	....	....	1	....	2
1859	....	....	....	....	....	....	....	....	1	....	....	....	1
1865	....	....	....	....	....	....	1	....	....	....	....	....	1
1870	....	....	....	....	....	1	....	....	1	....	....	....	2
1871	....	....	....	....	....	....	1	....	....	....	....	....	1
1874	....	....	....	....	....	....	....	....	....	....	1	....	1
1877	....	....	....	....	....	....	....	....	....	....	1	....	1
1880	....	....	....	....	....	....	1	....	....	1	....	....	2
1882	....	....	....	....	....	....	1	....	1	....	....	....	2
1883	....	....	....	....	....	....	....	....	1	1	....	....	2
1884	....	....	....	....	....	....	....	....	1	1	....	....	2
1885	....	....	....	....	....	....	1	....	1	2	....	....	4
1886	....	....	....	....	....	....	....	....	1	....	....	....	1
1887	....	....	....	....	....	....	1	....	....	1	....	....	2
1888	....	....	....	....	....	....	....	2	2	....	....	....	4
1889	....	....	....	....	....	....	....	1	....	....	....	....	1
1890	....	....	....	....	....	....	....	1	....	....	....	....	1
1891	....	....	....	....	....	....	....	2	....	....	....	....	2
1892	....	....	....	....	....	....	1	....	....	....	....	....	1
1895	....	....	....	....	....	....	....	....	1	....	....	....	1
1899	....	....	....	....	....	....	....	1	1	....	....	....	2
1902	....	....	....	....	....	....	....	....	....	....	....	1	1
1904	....	....	....	....	....	....	....	....	....	....	1	1	2
1906	....	....	....	....	1	....	....	....	....	1	1	....	3
1912	....	....	....	....	....	....	....	1	2	1	....	....	4
1913	....	....	....	....	....	....	....	1	....	....	....	....	1
1915	....	....	....	....	....	....	1	....	2	1	....	....	4
1917	....	....	....	....	....	....	....	....	2	1	....	....	3
1918	....	....	....	....	....	....	....	....	2	....	....	....	2
1919	....	....	....	....	....	....	....	....	1	1	....	....	2
1920	....	....	....	....	....	....	....	....	1	....	....	....	1
1921	....	....	1	....	....	....	....	....	2	2	....	....	5
1922	....	1	....	....	....	....	1	1	2	1	....	....	6
1923	1	....	1	....	....	....	....	....	....	....	....	....	2+
Total	1	1	2	....	1	5	10	14	31	22	7	3	97

TABLE 15. MONTHLY DISTRIBUTION OF STORMS IN THE EASTERN NORTH PACIFIC

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Number	1	1	2	0	1	5	10	14	31	22	7	3	97
Per cent	1	1	2	0	1	5.1	10.3	14.5	32.0	22.7	7.2	3	99.8

TABLE 16. AREA OF ORIGIN OF STORMS IN THE EASTERN NORTH PACIFIC, 1832-1922, BY MONTHS AND 5° SQUARES

		90- 95 W.	95-100 W.	100-105 W.	105-110 W.	110-115 W.	115-120 W.	120-125 W.	125-130 W.	130-135 W.	135-140 W.	140-145 W.	145-150 W.	150-155 W.	155-160 W.	160-165 W.	170-175 W.	Total
May	10-15 N.	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	1
June	10-15 N.	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	1
	15-20 N.	....	....	....	2	....	1	....	....	....	....	....	....	....	....	....	....	3
	Total	....	....	....	2	1	1	....	....	....	....	....	....	....	....	....	....	4
July	5-10 N.	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
	10-15 N.	....	....	....	1	1	1	....	....	....	....	....	....	....	....	....	....	3
	15-20 N.	....	....	....	....	....	2	....	....	....	....	....	....	....	....	....	....	2
	20-25 N.	....	....	....	....	1	1	....	1	....	....	....	....	....	....	....	....	3
	Total	1	....	....	1	2	4	....	1	....	....	....	....	....	....	....	....	9
Aug.	10-15 N.	....	1	....	....	2	5	1	....	....	....	....	....	....	....	....	....	9
	15-20 N.	....	....	....	1	....	2	1	....	....	....	....	....	....	....	....	....	4
	Total	....	1	....	1	2	7	2	....	....	....	....	....	....	....	....	....	13
Sept.	5-10 N.	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	1
	10-15 N.	1	....	4	....	....	1	....	....	....	1	....	....	....	....	....	....	7
	15-20 N.	....	1	3	2	1	1	1	....	....	....	1	....	....	....	....	....	10
	20-25 N.	....	....	1	....	1	....	1	2	....	....	....	....	....	....	....	....	5
	Total	1	1	8	2	3	2	2	2	....	1	1	....	....	....	....	....	23
Oct.	10-15 N.	2	1	....	....	....	1	....	....	....	....	....	....	....	....	....	....	4
	15-20 N.	....	....	2	3	....	....	....	....	....	....	....	....	2	....	....	....	7
	20-25 N.	....	....	....	5	1	....	....	....	....	....	....	....	....	1	....	....	7
	25-30 N.	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
	Total	2	1	2	8	1	1	....	....	....	1	....	....	2	1	....	....	19
Nov.	10-15 N.	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	1
	15-20 N.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....	2
	20-25 N.	....	....	....	2	....	....	....	....	....	....	....	....	....	1	....	1	4
	Total	....	....	....	2	....	....	1	....	....	....	....	....	....	1	2	1	7
Dec.	10-15 N.	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	1
	20-25 N.	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....	....	2
	Total	....	....	....	....	....	....	....	....	....	....	....	1	....	2	....	....	3
Grand Total		4	3	10	16	9	15	5	3	....	2	1	1	3	4	2	1	79

HURRICANES OF AUSTRALIA AND ADJACENT WATERS

In Australia the gathering of records of tropical cyclones is surrounded by the same conditions that prevail in the "Far East" and elsewhere: the paucity of observation stations; the deficiency of the records so far as continuity and length of term are concerned; and the difficulty of deciding whether or not a particular storm was severe enough to warrant its inclusion in a list. Observation stations are widely separated, especially in sparsely settled northern Australia. Even along the coast of central and southern Queensland many small cyclones pass inland from the sea, or outward from the vast continental interior without going near a meteorological station, or even a town. The briefness of the record is due, in part, to the fact that before the formation of the Commonwealth in 1900, there was far less cooperation among meteorological record observers than at present. And since 1900 the meteorological records for many outlying stations have not been continuous, for most of the observers are voluntary workers who have little time when a hurricane strikes them to record and send in meteorological data.

With reference to severity, the general rule in Australia, as elsewhere, has been to disregard storms that cause no great destruction. Indeed, faithful officials of the Commonwealth Weather Bureau have been publicly censored by other government officials for showing keen interest in approaching storms and issuing forecasts that alarmed certain citizens. The fact that a storm fails to demolish any town in that sparsely settled continent deprives it of merit! However, Mr. David Hodge, Chief Clerk of the Weather Bureau, and other officials who greatly assisted me in compiling the lists of Australian storms, agreed that it was desirable to include all well-developed cyclones of tropical origin, even if they were not destructive hurricanes, and to classify the storms with reference to their known severity, as "hurricane," "cyclone," "gale," and "tropical cyclone." The term "tropical cyclone" is applied to storms which caused no reported damage within Australia, although perhaps destructive not far away.

The compilation of lists of Australian tropical cyclones is further complicated by the frequent occurrence of tornadoes, thunder squalls, and the so-called "southerly buster." All of these storms may unroof houses, break trees, and locally do other damage resembling that caused by tropical cyclones. These local storms were eliminated from the lists in the following manner: The daily weather map was examined to see if there was isobaric evidence of a regular tropical cyclone. If not, record reports of even great local damage were usually omitted, in spite of the

recognized fact that many true tropical cyclones have a diameter of less than one hundred miles and that cyclones of such a size might pass across a sparsely settled region without giving clear isobaric evidence of their courses. The daily weather maps for thirty-one years, 1892 to 1922, inclusive, studied by me or by Mr. Hodge, give evidence of many storms. (See Table 17.)

The Australian Government has shown so much interest in my studies of Australian tropical cyclones that the Weather Bureau is soon to issue a bulletin on the subject. The following data and remarks are partly identical with statements to be found in that bulletin and are based in part on data there presented. In the bulletin lists of storms and considerable additional data, chiefly of local interest, are also given, including rather full notes as to the damage done by individual storms, and the amount of rainfall.

TABLE 17. HURRICANES IN AUSTRALIA AND ADJACENT WATERS BY YEARS AND MONTHS (THE RECORD FOR 1922 IS INCOMPLETED)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Month Not Given	Total
1839	....	....	1	....	....	....	....	....	....	....	1	....	....	2
1843	....	1	....	1	....	....	....	....	....	....	....	....	....	2
1850	....	....	....	....	....	....	....	....	....	....	....	....	1	1
1860	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1861	....	....	1	....	....	....	....	....	....	....	....	....	....	1
1862	1	....	1	....	....	....	....	....	....	....	....	....	....	2
1867	....	....	2	1	....	....	....	....	....	....	....	....	....	3
1869	....	....	1	1	....	....	....	....	....	....	....	....	....	2
1870	1	3	....	1	....	....	....	....	....	....	....	1	....	6
1871	....	....	2	....	2	....	....	....	....	....	1	....	....	5
1872	1	2	1	....	....	....	....	....	....	....	....	1	....	5
1873	....	....	....	1	....	....	....	....	....	....	....	....	....	1
1874	....	....	....	....	....	....	....	....	1	....	....	....	....	1
1875	....	....	1	....	....	....	....	....	....	....	....	1	....	2
1876	....	2	1	....	....	1	....	....	....	....	....	1	....	5
1877	....	2	....	....	....	....	....	....	....	....	....	....	....	2
1878	1	1	2	....	....	....	....	....	....	....	....	2	....	6
1879	2	....	....	....	....	1	....	....	....	....	....	....	....	3
1880	2	....	....	....	....	....	....	....	....	....	....	....	....	2
1881	2	....	1	....	....	....	....	....	....	....	....	....	....	3
1882	1	1	1	1	....	....	....	....	....	....	....	....	....	4
1883	....	2	....	....	....	....	....	....	....	....	....	....	....	2
1884	2	2	1	....	....	....	....	....	....	....	....	....	....	5
1885	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1886	....	....	....	1	....	....	....	....	....	....	....	....	....	1
1887	....	1	2	1	....	....	....	....	....	1	....	....	....	5
1888	1	1	....	1	....	....	....	....	....	....	....	1	....	4
1889	....	1	1	....	....	....	1	....	....	....	....	....	....	3
1890	2	....	3	....	....	....	....	....	....	....	....	....	....	5
1891	....	....	1	....	....	1	....	....	....	....	....	....	....	2
1892	1	....	....	1	....	....	....	....	....	....	1	1	....	4
1893	1	3	....	....	....	....	....	....	....	....	....	1	....	5

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Month Not Given	Total
1894	2	1	1	....	....	....	....	....	....	....	....	....	....	4
1896	1	....	....	....	....	....	....	....	....	....	....	....	....	1
1897	1	....	....	....	....	....	....	....	....	....	....	2	....	3
1898	....	2	2	1	....	....	....	....	....	....	....	....	....	5
1899	1	1	2	1	....	....	....	....	....	....	....	....	....	5
1900	....	....	1	....	....	....	....	....	....	....	....	....	....	1
1901	1	1	....	....	....	....	....	....	....	....	....	....	....	2
1902	....	1	....	1	....	....	....	....	....	....	....	....	....	2
1903	2	....	1	....	....	....	....	....	....	....	....	....	....	3
1904	....	....	1	1	....	....	....	....	....	....	....	....	....	2
1905	....	1	....	....	....	....	....	....	....	....	....	....	....	1
1906	1	....	1	....	....	....	....	....	....	....	....	....	....	2
1907	2	....	1	....	....	....	....	....	....	....	1	....	....	4
1908	1	1	1	2	....	....	....	....	....	....	1	1	....	7
1909	2	2	1	1	....	....	....	....	2	....	....	....	....	8
1910	2	....	1	....	....	....	....	....	....	....	1	1	....	5
1911	1	2	2	....	....	....	....	....	....	....	1	....	....	6
1912	2	1	3	3	....	1	1	....	....	....	1	1	....	13
1913	5	2	....	1	1	....	....	....	....	....	....	1	....	10
1914	2	1	1	....	....	1	....	....	1	1	....	1	....	8
1915	....	2	3	1	....	....	....	....	....	....	....	2	....	8
1916	2	2	2	1	2	....	1	....	1	1	1	1	....	14
1917	1	....	2	1	....	....	....	....	....	....	....	2	....	6
1918	1	2	3	1	....	....	....	....	....	....	....	....	....	7
1919	....	....	3	1	1	....	1	....	....	....	....	....	....	6
1920	....	3	1	2	....	....	....	....	....	....	....	1	....	7
1921	3	1	1	1	1	2	2	....	....	1	1	....	....	13
1922	2	....	1	....	....	....	....	....	....	....	....	....	....	3
Total	54	49	58	29	7	7	6	0	5	4	10	22	1	252

FREQUENCY AND MONTHLY DISTRIBUTION

Table 17 gives lists of the "hurricanes" by years and months as recorded in Australia and its adjacent waters (longitudes 100° to 160° E.).

Table 18 shows that the main hurricane season in the Australian region extends from December to April, during which five month period about five-sixths of the storms occur. (See also fig. 8.) About three-fifths of the storms occur in January, February, and March. During the seven months, May to November, inclusive, storms are rare, but rather evenly distributed, with the exception that no severe tropical cyclone has been recorded for August. Although some tropical cyclones cross the entire continent and more or less strongly affect the weather of much of Australia, most of the storms notably influence only part of the continent. For meteorological study it is desirable to divide the Commonwealth into regions, using the political divisions: Queensland, Northern Territory, and Western Australia; and to consider also the storminess of certain nearby areas, outside of Australia.

In Queensland, the best known of the regions, and apparently the

stormiest, the main hurricane season hardly commences before Christmas. Two-thirds of these severe storms occur in the three months, January, February, and March, and four-fifths in the five months, December to April, inclusive. It cannot be said, however, that there is no risk from hurricanes during the other seven months. Of the especially severe storms of the period 1870-1922, three occurred in June, one in September, and one in November. Including the less severe type of storms, every month has had four or more except August, which has had one. In Northern Territory, 60 per cent of the storms occurred in the three months, January, February, and March; the remainder in November, December, and April. None has yet been recorded for the cooler six months, May to October. In Western Australia, 72 per cent of the storms occurred in January, February, and March, and 93 per cent in the five months, December to April, inclusive. Hurricanes have been recorded, however, in July, September, and October.

TABLE 18. MONTHLY DISTRIBUTION OF 251 TROPICAL CYCLONES IN AUSTRALIA AND ADJACENT WATERS

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Number	54	49	58	29	7	7	6	0	5	4	10	22	251
Per cent	21.5	19.5	23.0	11.5	2.8	2.8	2.4	0	1.9	1.5	3.9	8.8	99.6

As to the month of greatest storminess, Table 19 indicates a slight regional difference. The stormiest month in Western Australia is January, with February second. January has nearly twice as many storms as March. In Northern Territory, March is first, and February second. In Queensland January and March are equally subject to hurricanes. Six-sevenths of the severe storms recorded near Timor occurred in April, while in the eastern Indian Ocean, February and March together have had nearly two-thirds of the recorded storms.

During the decade 1912-1921 there was an average of 6.2 severe storms a year in Queensland and an average of about 8.5 storms which did not produce damaging gales in Queensland itself, although many of them caused gales at sea not far away. Northern Territory and Western Australia each have an average record of about 1.5 severe storms a year. In nearby portions of each of the adjacent oceans there have been averages of fully two storms a year, making a total for this general region of more than twelve severe tropical cyclones a year. For a discussion of tracks, velocity, duration, and prediction of Australian cyclones see pages 76, 83, 104.

TABLE 19. MONTHLY DISTRIBUTION OF AUSTRALIAN TROPICAL CYCLONES BY STATES

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Queensland												
Hurricanes and cyclones	29	22	29	12	6	6	5	....	4	4	2	8
Lesser disturbances	12	15	12	10	9	7	6	1	....	4	5	7
Percentage of all cyclones	20	17	20	10	5	6	4	0.5	2	4	3	9
Northern Territory												
Mainland	8	6	9	2	....	....	....	....	....	....	4	5
Near Timor	....	....	1	6	....	....	....	....	....	....	....	....
Western Australia												
Mainland	19	17	15	8	....	....	1	....	1	....	3	7
Percentage	27	24	21	11	....	....	1	....	1	....	5	10
Eastern Indian Ocean	3	7	7	2	2	....	....	....	....	....	1	1

LATITUDE AND LONGITUDE OF ORIGIN

Table 20 gives the approximate origin or place of first record of 245 Australian tropical cyclones. It reveals a tendency toward a seasonal variation in the place of origin. From November to April, inclusive, slightly over half of the storms are first noted in relatively low latitudes, 5° to 15° S.; in the other six months about five-sixths of the storms make their appearance in latitudes greater than 15°. More cyclones are first reported from the interior of Australia during the cooler six months, May to October, than for the rest of the year. Many of these apparently originated over the Gulf of Carpentaria. Especially disastrous hurricanes are recorded as follows:

1875, December 24; Exmouth Gulf, Western Australia; 69 lives lost.
1881, February 9; near Roebourne, Western Australia; 12 vessels lost.
1884, January 30; Bowen, Queensland; nearly the entire town unroofed.
1887, April 22; Ninety Mile Beach, Western Australia; more than 200 lives lost.
1894, January 9; Roebourne and Cossack, Western Australia; 40 lives lost.
1896, January 26; Townsville, Queensland; much damage over a wide area.
1897, January 6-7; Darwin, Northern Territory; many lives lost; estimated damage, 150,000 pounds; Palmerston demolished.
1899, March 5; Bathurst, Queensland; 300 lives lost.
1907, January 19; Cookstown, Queensland; estimated damage, 20,000 pounds.
1908, April 26; Lagrange Bay, Western Australia; 50 lives lost; property valued at 140,000 pounds destroyed.
1908, November 9; Broome, West Australia; perhaps 50 lives; property loss, 20,000 pounds.
1910, November 19; Broome, West Australia; 40 lives lost; 26 luggers destroyed.
1911, March 16; Port Douglas district, Queensland; Port Douglas demolished; Cains and Innisfail damaged.
1913, January 29; Cairns, Queensland; severe damage at Innisfail and Cairnes where record floods occurred.

1918, January 20; Mackay, Queensland; 30 lives lost; property damaged, 1,000,000 pounds.
1918, March 9; Innisfail, Queensland; town demolished.
1920, February 2; Port Douglas, Queensland; severe as far west as Victoria River, Northern Territory.

TABLE 20. PLACE OF ORIGIN OF HURRICANES IN AUSTRALIA BY MONTHS AND 5° SQUARES

		100-105 E.	105-110 E.	110-115 E.	115-120 E.	120-125 E.	125-130 E.	130-135 E.	135-140 E.	140-145 E.	145-150 E.	150-155 E.	155-160 E.	Total
Jan.	10-15 S.	1	....	1	1	1	5	3	1	2	9	5	2	31
	15-20 S.	....	....	1	8	4	1	....	....	....	2	3	1	20
	20-25 S.	....	....	1	....	....	....	....	1	....	....	2	1	5
	Total	1	....	3	9	5	6	3	2	2	11	10	4	56
Feb.	10-15 S.	3	....	....	1	1	1	3	2	....	3	1	8	23
	15-20 S.	....	....	3	7	2	....	....	1	....	....	2	3	18
	20-25 S.	....	1	3	....	....	....	....	1	1	....	....	....	6
	Total	3	1	6	8	3	1	3	4	1	3	3	4	47
Mar.	10-15 S.	1	1	....	1	5	4	3	1	1	3	3	7	30
	15-20 S.	1	2	....	2	4	1	....	2	....	3	1	4	20
	20-25 S.	....	....	2	....	....	....	....	....	1	....	....	2	5
	Total	2	3	2	3	9	5	3	3	2	6	4	13	55
Apr.	5-10 S.	....	1	....	....	1	6	....	....	....	....	....	....	8
	10-15 S.	....	....	1	2	2	....	1	1	....	1	....	3	11
	15-20 S.	....	....	1	2	....	....	....	....	....	....	1	1	5
	20-25 S.	....	....	....	....	....	....	....	....	....	....	....	2	2
	Total	....	1	2	4	3	6	1	1	....	1	1	6	26
May	10-15 S.	....	....	....	1	....	....	....	....	....	....	....	....	1
	15-20 S.	1	....	....	....	....	....	....	....	....	....	....	2	3
	20-25 S.	....	....	....	....	....	....	....	....	....	....	....	5	5
	Total	1	....	....	1	....	....	....	....	....	....	....	7	9
	10-15 E.	....	....	....	....	....	....	....	1	....	1	....	1	3
June	15-20 E.	....	....	....	....	....	....	....	....	....	1	....	....	1
	20-25 E.	....	....	....	....	....	....	....	....	....	....	1	2	3
	Total	....	....	....	....	....	....	....	1	....	2	1	3	7
July	10-15 E.	....	....	....	....	1	....	....	....	....	....	....	....	1
	15-20 E.	....	....	....	....	....	....	....	....	....	....	....	1	1
	20-25 E.	....	....	....	....	....	....	....	....	....	1	....	3	4
	Total	....	....	....	....	1	....	....	....	....	1	....	4	6
Aug.	None	....	....	....	....	....	....	....	....	....	....	....	....	....
Sept.	15-20 E.	....	....	....	1	....	....	....	....	....	....	1	1	3
	20-25 E.	....	....	....	....	....	....	....	1	....	....	1	....	2
	Total	....	....	....	1	....	....	....	1	....	....	2	1	5

		100-105 E.	105-110 E.	110-115 E.	115-120 E.	120-125 E.	125-130 E.	130-135 E.	135-140 E.	140-145 E.	145-150 E.	150-155 E.	155-160 E.	Total
Oct.	15-20 E.	....	....	....	....	....	....	....	1	....	....	2	1	4
Nov.	10-15 E.	1	....	....	....	2	2	4	....	....	....	....	....	9
	15-20 E.	....	....	....	....	....	....	....	....	....	1	....	....	1
	Total	1	....	....	....	2	2	4	....	....	1	....	....	10
Dec.	5-10 E.	....	1	....	....	1	....	....	....	....	2	....	....	4
	10-15 E.	....	....	....	1	1	1	3	1	....	....	....	1	8
	15-20 E.	....	....	1	1	....	....	....	....	1	....	2	1	6
	20-25 E.	....	....	....	....	....	....	....	1	....	....	1	....	2
	Total	....	1	1	2	2	1	3	2	1	2	3	2	20
Grand	Total	8	6	14	28	25	21	17	15	6	27	26	52	245

HURRICANES OFF THE WEST COAST OF AUSTRALIA

The storms in the following list are recorded by Schuck (158) except the storm of March, 1904, which is reported in the Australian Directory (9). Although none of these storms is known to have caused damage in Western Australia, the list suggests the probabilities of severe cyclones in nearby waters:

DATE	EAST LONGITUDE	SOUTH LATITUDE
1860, Feb. 28-29	105 to 100	12 to 16
1861, Mar. 12-15	101 to 90	11 to 14
1862, Jan. 9-11	104 to 96	13 to 23
1862, Mar. 1- 3	101 to 95	19 to 24
1869, Mar. 4	109	19
1870, Feb. 13-18	112 to 111	19 to 24
1870, Feb. 21-27	108 to 109	21 to 31
1870, Apr. 14-20	107 to 104	7 to 19
1871, Mar. 26-28	108 to 100	15 to 20
1871, May 27-29	102	16
1871, May 30-31	118	14
1871, Nov. 6- 9	100 to 88	4 to 8
1872, Feb. 20-23	103 to 95	13 to 18
1873, Apr. 17	111	15
1878, Feb. 26-29	122 to 115	18 to 16
1878, Mar. 1- 3	110	30
1878, Dec. 27-28	106	6
1879, Jan. 22-25	124 to 119	15 to 11
1881, Jan. 7	114	21
1881, Mar. 7- 8	117	20
1883, Feb. 6- 9	104	9
1884, Feb. 24	112	22
1904, Mar.	108	16

There are several conspicuous gaps in this list. During the years for which one or more severe cyclones are reported, there is an average of

two storms a year. One year has four, and two years have three each. This monthly distribution is different from that shown in the list of storms for Western Australia. February and March lead in the number of storms, with 7 each out of 23; January has 3; April and May 2 each, and November and December one each. Combining the list of hurricanes off the west coast of Australia with the list of storms for Western Australia, the totals are: January, 24; March, 22; April, 13; May, 2; July, 1; September, 1; November, 3, and December, 7.

HURRICANES NEAR TIMOR, DUTCH EAST INDIES

Braak (19) has published the following list of hurricanes occurring near Timor which lies but a few degrees distant from Northern Territory, and near the sailing route from Darwin to Singapore or India. It is altogether probable that hurricanes occur no more frequently near Timor than in similar nearby latitudes. All of these storms moved west-southwest. The tracks of five of them are shown on figure 16.

1778, April 2; Banda, north of Timor (severe).
1843, April 21-23; southwest end of Timor; 75 lives lost.
1850, ...; Kei Island, west of Timor.
1908, April 28-May 2; passed near northwest tip of Timor; 60 lives lost on Kissa Island.
1918, April 9-12; passed along southeast side of Timor.
1919, April 6-10; passed along southeast side of Timor.
1920, March 24-25; crossed northwest tip of Timor.
1920, April 7-13; crossed northwest tip of Timor.

TROPICAL CYCLONES IN THE EASTERN SOUTH PACIFIC

Little is known about the tropical cyclones of the vast southeastern quarter of the Pacific; the 60 degrees of longitude between the Tuamotus and South America. The paucity of records for this region has commonly been interpreted as indicating that hurricanes are lacking, or very rare. This interpretation is in accord with the hypothesis that tropical cyclones originate only on the western sides of the oceans. But, this hypothesis should be abandoned, for it is now known that tropical cyclones do originate in considerable numbers on the eastern sides of three oceans (pp. 47, 57, 84). The fact that the southeastern North Pacific is now recognized as a storm region of major importance, although until recently it was largely ignored, is of especial significance in the present connection, as it adjoins the eastern South Pacific.

The conclusion that few records for this region indicate few storms is also in accord with the hypothesis that tropical cyclones develop only along the doldrums. Wind records indicate that the doldrums remain north of the area between the Tuamotus and South America. In fact, the published charts show that the southeast trades are exceptionally persistent and strong south of the Equator. But the charts show the same condition off the west coast of Australia, where hurricanes develop. The paucity of recorded storms may very well be related to the paucity of observers. East of the Tuamotus, islands are lacking in latitudes 5° S. to 23° S. Pitcairn, Easter, and other islands south of this zone are seldom visited, and except along the South American coast few ships traverse this region.

Tropical cyclones are not unknown in the eastern South Pacific. The official German "Atlas of the Pacific" shows the track of an August hurricane, extending southeast from about latitude 17° S. longitude 120° W. Ships along the adjacent South American coast occasionally encounter storms of some severity. For example, on August 26, 1922, the Chilean steamer Itata sank in a severe gale near Coquimbo (latitude 30° S.), with the loss of 301 lives (8).

Frequently along the coast of northern Chile there is such a heavy swell that ships have difficulty in reaching open ports. Such strong swells usually are caused by a tropical cyclone. The fact that hurricanes themselves are not recorded as breaking with the same fury on the Chilean

and Peruvian coast as on the west coasts of Mexico and Australia, may possibly be partly due to the protective effect of the denser air overlying the comparatively cold waters of the Peruvian current.

Brooks (*22*) mentions the following hurricanes at Valparaiso: 1783, June 3-15, from the north; 1827, June 5, lowest barometer since 1812; 1856, March 11-13, from the north; 1864, June 2-9.

CYCLONES IN THE CENTRAL NORTH PACIFIC

Some storms of no slight severity affect the Hawaiian islands; on December 3-14, 1918, many trees were uprooted in Honolulu, and on January 13-14, 1923, the city experienced a cyclonic wind of fifty-six miles an hour. Most of the recorded storms in the southeastern quarter of the North Pacific moved northward out of the Tropics at a considerable distance east of Hawaii (p. 47), but many lesser cyclonic disturbances move northward near those islands. For the three years 1920-1923, Hurd (95) and Tingley (180, 181) have reported 15 depressions or more intense tropical disturbances passing northward or northeastward near the Hawaiian islands (longitude 140° to 180° W.). In the zone of the same width to the west, longitudes 140° to 180° E., just east of the eastern limits usually assigned to the typhoon region, 11 tropical cyclones were reported during the same period (1920-1923). Relatively more of these disturbances, however, are severer storms than are those farther east. Several are described as severe typhoons.

The reported disturbances in these two regions are shown in the following lists (the figures in parentheses refer to the bibliography):

TROPICAL CYCLONIC DISTURBANCES PASSING NEAR THE HAWAIIAN ISLANDS IN THE THREE YEARS APRIL, 1920-MARCH, 1923

Jan. 28, 1922; vigorous depression moved north from about latitude 20° N., longitude 170° W. (181, p. 13).
Jan. 13-14, 1923; cyclone damaged Hawaiian Islands; wind 56 miles an hour at Honolulu (95, p. 98).
Jan. 20, 1923; depression moved north between Hawaii and Midway islands (181, p. 98).
Feb. 16, 1922; low moved north just east of Midway island (181, p. 99.
Mar. 18-19, 1922; low moved east-northeast from Hawaii to California; gale on March 19 (181, p. 15).
Mar. 26, 1923; cyclone moved north near Hawaii (95, p. 149).
July 21-22, 1921; east-southeast gale experienced from longitude 177° E. to 177° W. in latitude 30° (182, p. 417).
Sept. 20-30, 1921; east-northeast gale in latitude 30° N., longitude 180° W. (182, p. 518).
Oct. 5, 1921; low moved north from Hawaii (182, p. 579).
Oct. 9-10, 1921; south-southeast gale at Midway; cyclone moved north-northeast (182, p. 580).
Oct. 17, 1921; depression formed just north of Hawaii (182, p. 580).
Nov. 15 and 20, 1922; two depressions moved north from near Hawaii (39, p. 598).
Nov. 26, 1922; depression moved north from near Midway island (39, p. 598).
Dec. 22-25, 1920; south-southwest gale experienced from Midway island to Hawaii (182).
Dec. 24-25, 1921; depression moved from near Hawaii to California (182, p. 679).

TROPICAL CYCLONES IN LONGITUDES 140° TO 180° E., LATITUDES 5° TO 30° N.

Mar. 22-27, 1923; typhoon moved north from about latitude 7° N., longitude 150° E. (95, p. 149 and fig. 3).
Apr. 11-12, 1921; cyclonic gale latitude 26° N., longitude 160°-165° E. (182, p. 252).
May 4-7, 1920; cyclone west of Midway island; strong gale (181, p. 292).
July 21-22, 1921; gale at and west of Midway island (182, p. 417).

Sept. 5-6, 1920; typhoon moved north, passed about latitude 25° N., longitude 170° E. (181, p. 543).
Sept. 12-13, 1920; typhoon, latitude 24° N., longitude 152° E. (181, p. 543).
Oct. 2-5, 1921; typhoon, latitude 10° N., longitude 145° E.; soon recurved (182, p. 579).
Oct. 8 and 28, 1921; typhoons developed near longitude 145° E. (39, p. 598).
Nov. 16, 1922; typhoon passed going northeast, latitude 30° N., longitude 160° E. (39, p. 598).
Dec. 16, 1920; typhoon devastated Yap and was destructive as far east as longitude 161° E., latitude 5° N. (181, p. 725).

These two lists including 27 tropical cyclonic disturbances in the Central North Pacific, occurring in a three-year period, suggest that an average of at least nine such disturbances is to be expected annually. October is accredited with nearly one-fourth of the disturbances and November with one-seventh; but each of four other months, January, March, September, and December, has one-ninth, or an average of one cyclonic disturbance a year. The only months not represented in the lists are June and August. As August lies between two months of considerable cyclonic activity, it is probable that a somewhat longer record would include an August cyclone. Indeed, since this discussion was completed, a somewhat detailed account of a typical hurricane encountered on August 30, 1923, in longitude 165° W., latitude 21° N., has been published by Blair (15).

A considerable number of the tropical cyclones of the Central North Pacific are severe storms. For example, the Deutsche Seewarte (48, p. 245) reports that during a 25-year period, 15 severe typhoons affected Guam (longitude 145° E., latitude 12° N.); two in February, three in April, one in June, one in September, and eight in November, and lists nine severe typhoons in the Marshall islands, longitude 165°-172° E. Coronas (38) reports that five of the remarkably severe typhoons that crossed the Philippines in the eleven years 1908 to 1918, inclusive, had their origin to the east of longitude 145° E.

A tropical cyclone severely damaged the eastern Carolines on April 20-22, 1905. Out of 2150 houses on the island of Ponape (latitude 7° N., longitude 158° E.), only one remained standing. The storm caused great destruction still further east, and south; all of the islands in that direction, including Kusaie (latitude 5° N., longitude 163° E.), suffered severely; it then moved westward, crossing Luzon on April 29th, and entered the China Sea April 30th. This storm is notable, not only because it was very destructive far out in the Pacific and in very low latitude, but also because its velocity of progression traveling westward decreased gradually for several days from twelve to seven miles an hour. Newnham (135, pp. 315, 318) reports a similar decrease in the typhoon of June 2-7, 1903, and in other storms, but it is unusual. The storm of March, 1923, was accompanied by winds exceeding 156 miles an hour at Guam (fig. 3).

CYCLONES NEAR THE EQUATOR, ESPECIALLY IN THE EAST INDIES

It has usually been assumed that the small deflectional effect of the earth's rotation near the Equator prevents the development of cyclonic storms there. Instead of circling round and round, the air tends to flow directly in towards a depression and fill it. This assumption is so plausible that the few tropical cyclones near the Equator have been largely ignored. Indeed, Milham (124, p. 247) and some other writers state or imply that tropical cyclones cannot occur within eight degrees of the Equator. The records are not in accord with this assumption. Table 21, based on available charts and lists, shows for the five years, 1908-1912, inclusive, 30 typhoons are recorded as having centers within eight degrees of the Equator. The number each year ranged from four in 1908 to eight in 1910. I was informed by Director Okada of the Japanese Imperial Marine Observatory that the meteorological conditions at Jaluit indicate typhoons west and southwest of Jaluit (latitude 6° 8′, longitude 170° E.) Of the storms listed in Table 21, that of October 22, 1891, crossed latitude 10° N., in longitude 98° E., and extended to Calcutta; that of October 16, 1891, reached the Bay of Bengal, crossing latitude 10° N., in latitude 122° E.; that of December 30, 1918, is reported as the end of a previous storm.

TABLE 21. TYPHOONS WITH CENTERS 5° TO 8° FROM THE EQUATOR, BY MONTHS

	Lat.	Long.		Lat.	Long.
Jan. 8, 1907	8	136	June 11, 1894	6	132
1, 1916	7	150	4, 1895	7	137
13, 1916	8	128	2, 1896	7	137
22, 1916	7	128	30, 1905	6	169
			10, 1914	8	133
Feb. 13, 1911	8	136	24, 1914	8	140
25, 1911	6	142	23, 1918	8	144
Mar. 6, 1892	8	130			
18, 1909	8	138	July 5, 1881	8	124
13, 1910	8	138	12, 1895	7	145
			22, 1895	7	138
Apr. 8, 1918	6	143	30, 1896	8	136
			12, 1913	8	133
May 3, 1891	5	132			
6, 1896	7	135			
23, 1908	8	127	Aug. 12, 1880	7	120
1, 1910	7	139	19, 1892	5	133
3, 1910	8	137	19, 1909	8	143
26, 1916	7	124	19, 1913	8	145

	Lat.	Long.		Lat.	Long.
Sept. 24, 1897	8	133	18, 1912	7	143
10, 1901	8	133	22, 1912	7	143
19, 1908	7	137	26, 1912	7	140
6, 1910	8	116	1, 1920	7	141
		}			
Oct. 2, 1880	5	122	Dec. 1, 1892	5	125
22, 1891	7	118	12, 1900	4	139
13, 1897	7	140	18, 1905	7	150
16, 1897	7	140	2, 1908	7	143
29, 1904	5	130	3, 1908	7	134
26, 1909	8	138	3, 1909	7	134
26, 1910	8	142	15, 1909	5	143
10, 1911	7	142	1, 1910	7	137
25, 1915	7	150	19, 1910	8	138
		}	2, 1911	8	145
Nov. 8, 1892	6	125	3, 1911	6	143
9, 1897	8	115	1, 1912	7	141
12, 1909	8	138	2, 1912	8	145
6, 1910	8	138	20, 1918	6	146
3, 1912	7	140	30, 1918	7	105

In regard to the severity of some sub-equatorial typhoons the following quotations from Hurd (92) are pertinent:

> It sometimes happens that typhoon-like storms, lasting for three or four days, break upon the Gilbert islands, near the Equator (latitude 4° N., to 3° S.) and longitude 174° E. The strong shifting winds, though of rare occurrence, inspire the natives with such fear that they prop their huts with stakes and tie them down to prevent them from blowing away. A brief account comes to us of a typhoon which visited Strong Island in latitude 5° 12′ N., longitude 163° E., during the early part of the nineteenth century and inflicted such destruction upon the breadfruit trees, the chief source of sustenance to the islanders, that a famine ensued which carried off nearly all the inhabitants. The island of Ponape, about 300 miles to the northwestward, in the Carolines, was at the same time similarly visited.

The severe damage on Kusaie Island and on Ponape Island by the typhoon of April 20, 1905, is mentioned on page 62.

A hurricane did great damage in the southern Marshall Islands (latitude 6° N.) on June 30, 1905. The barometer at Jaluit fell to 27-6 inches (935 millebars), and the accompanying storm wave rose to a height of 46 feet at Mille (188, p. 541).

Concerning a typhoon which crossed northern Borneo (latitude 6° N.) on October 31, 1904, Algué (3, p. 165) reports as follows:

> This was a very destructive typhoon . . . very well developed and of great intensity . . . we think the minimum must have been below 742 mm. . . . The waves dislodged great rocks, some of them more than three cubic meters in size. . . . The storm destroyed a great part of the fruit trees and . . . wrought havoc among trees of every kind. . . . Numerous buildings were laid in ruins.

A typhoon which crossed Mindanao on November 28, 1912, is described by Algué (3, pp. 402-405), and others as having been of terrible intensity and destructiveness in latitude 7° N.

South of the Equator in similar latitudes and longitudes, fewer tropical cyclones are recorded. However, eight hurricanes have been reported by Braak from Timor and vicinity (latitude 8°-10° S., longitude 124°-127° E.) (19, p. 93). The fact that four of these hurricanes occurred during the three years just preceding the compilation of the record suggests that tropical cyclones are not so very rare in this area.

East of Papua, records of two December hurricanes in the five degree square longitude 145°-150° E., latitude 5° to 10° S., have come to light, and one January storm in the eastern Solomons, longitude 160°-165° E., latitude 5°-10° S.

Ellice Islands (latitudes 5½°-11°; longitudes 176°-180° E.) experienced "a very severe hurricane" in February, 1891—a storm which later caused great destruction in Tonga—and was traced for over 1500 miles (20). Atafu, Tokelau Islands (latitude 8° 32′ S., longitude 172° 31′ W.) was devastated by a hurricane on January 7, 1914 (20).

In the Indian Ocean, tropical cyclones are reported in considerable numbers within ten degrees of the Equator. Newnham (135, p. 20), charts the tracks of fifteen in the South Indian Ocean, and Schück (159) tabulates eleven tropical cyclones as having occurred within five degrees of the Equator in the South Indian Ocean; three in November, two each in June and July, and one each in March, April, May, and October. He classifies 62 cyclones as having originated in latitudes 5°-10° S. during the years 1848 to 1905. These occurred in all months except July, August, and September.

In the North Indian Ocean likewise, tropical cyclones are by no means lacking within ten degrees of the Equator. Newnham (135) lists thirteen which developed in that part of the Bay of Bengal during the thirteen years, 1900-1912. Five of these are shown as originating on or just south of the eighth parallel, and two in latitude 4. According to Schück, (159) nearly one-eighth of the storms of the Arabian Sea originate within ten degrees of the Equator.

COURSES FOLLOWED BY TROPICAL CYCLONES

NORMAL COURSES

Perhaps a majority of the tropical cyclones of the Pacific move westward and poleward, west-northwest in the Northern Hemisphere, and west-southwest in the Southern Hemisphere, until they have reached latitude 20°-30°, and then recurve and move eastward, often north-northeast in the Northern Hemisphere (northwest, north, or northeast) and south (southwest, south or southeast) in the Southern Hemisphere. Figures 9-16 and 18-19 afford several illustrations of these courses.

Two other paths are very ferquently followed, and may be compared with the two main parts of the "normal course" just outlined. Many tropical cyclones after traveling westward a greater or lesser distance die out without recurving. (See figures 10, 11, 16.) On the other hand, many other storms move almost directly out of the Tropics, northward (northwest, north, or northeast) in the Northern Hemisphere and southward (southwest, south, or southeast) in the Southern Hemisphere. After reaching mid-latitudes, many such storms recurve eastward, following a course similar to that of the normal storm after the commencement of the recurve. Others apparently move almost straight, northwest, north, or northeast, in the Northern Hemisphere, and southwest, south, southeast in the Southern Hemisphere. They appear to be especially numerous in the south Pacific and Indian Ocean.

ABNORMAL COURSES

Of abnormal or rarely traversed courses there are several types. The more important are the following:

(a) Those that are normal except that they recurve in low latitudes, less than twenty degrees from the Equator, with the result that the storm moves eastward well within the Tropics, instead of westward or poleward.

(b) Those which instead of moving away from the Equator as they travel westward, move into somewhat lower latitudes as they proceed, until they die out—a type well represented in the "Far East" and present also in the eastern North Pacific and in the western South Pacific.

(c) Those in the track of which loops are occasionally formed. Mitchell (127) states that in the West Indies region, wherever the paths describe a loop it is always to the left, opposite to the direction of normal recurve. This constancy of direction suggests the operation of some physical law. Ferrel's law of diversion would appear likely to cause the

loop to be to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. But the loop described by the hurricane of January 22-24, 1922, near Norfolk Island, was to the right, or directly opposite to the loop movement characteristic of the West Indian storms. The typhoon of August 29-September 4, 1910, however, described a complete loop to the right between Formosa and Japan on September 3-4, according to a report by Froc, and a hurricane off the Queensland coast, charted by Taylor (178), illustrated Ferrel's law in direction of recurve.

(d) Several other types of abnormal courses are charted in figures 10, 14, 15, and 16: (1) sinuous courses; (2) very sharp recurves, the storm passing eastward only a short distance from its westward course; in Fiji, a storm passed twice over the same belt, without making a loop of any considerable size; (3) recurves toward the Equator instead of away from it, to the left instead of to the right, in the Northern Hemisphere. This type is similar to type "c" except that instead of having a small loop, it forms only a part of a large one. Figures 10 and 12 include several tracks of this type along which the storm moved several degrees towards the Equator.

Special rare variations in storm tracks are bifurcation and convergence. Two well-developed cyclones may combine to form one. The combining of feeble disturbances is common. Likewise, some well-developed cyclones apparently divide into two independent, comparable storms, each of which thereafter follows an independent course. Algué (1) suggests that topographic barriers may be the cause, but the storms he considers do not make this explanation altogether satisfactory.

Secondary whirls sometimes develop within a cyclone and produce destructive winds far from the center of the main cyclone. Algué (4) has repeatedly observed such secondary centers in the Philippines. Okada (137) reports that not rarely two or three secondary centers occur within a typhoon.

EFFECT OF MOUNTAINS

It is stated in some standard meteorologies that tropical cyclones can not cross a mountain range as much as 3,000 feet (916 m.) high. This statement is, however, disproved in Tiawan (Formosa), the Philippines, Japan, and elsewhere, where many typhoons cross mountains of greater height than this. Mountainous Formosa appears to deflect many typhoons which approach it at a small angle, and according to Froc (67), may cut the typhoon in two; but other storms cross Formosa with no apparent regard for its mountains, the highest of which reaches an elevation of 13,000 feet (4,000 m.). Okada (137) reports that studies made on

lofty Fuji and on the higher mountains of Formosa indicate that the height of several typhoons passing these stations was approximately 16,000 to 20,000 feet (5 to 6 km.).

Although typhoons commonly weaken decidedly as soon as they come upon the land, both Froc (67) and Okada (137) have observed many in southeast China which maintained most of their force until they encountered lofty mountains. In Australia also, while a weakening is common, many storms remain destructive for long distances over the land.

TYPHOON TRACKS

The extremely valuable atlas of typhoon tracks compiled by Froc (65) includes so much detail as to be somewhat confusing, and Doberck's chart, commonly reproduced in text books, is based on very inadequate data. For use in this paper it has been found desirable to construct the chart of average typhoon tracks shown in figure 9. This chart is based on the twenty-one maps in Froc's Atlas. For each month one average track is drawn for each 25 tracks given by Froc. The 24 tracks thus obtained represent with reasonable accuracy the average number of typhoons, occurring annually during the period 1893 to 1918, inclusive. The monthly distribution is also indicated. The greatest inaccuracy arises from the necessity of omitting the few storms which follow very aberrant courses. To represent these figure 10 has been prepared.

Figure 9 shows that, on the average, the typhoons are first observed somewhere east of the Philippines. About one-third crosses the Philippines, while another third moves rather promptly northward and northeastward, passing not far east of Japan. The remaining third moves westward to the north of the Philippines and then turns northward across the east China Sea and Sea of Japan, or across Japan itself. Among the storms which cross the Philippines, many continue west-northwestward to the Asiatic coast, and a few recurve in the south China Sea and move north-northeast toward Japan.

The courses followed by the average storms differ notably with the seasons (fig. 9). From January to April the storms usually move northward to the east of the Philippines, Formosa, and Japan, although the easternmost tip of Japan is normally crossed by a March storm.

During May and June two storms cross the Philippines, one continuing to south China, the other recurving and crossing Japan from south to north. A third storm recurves promptly and strikes only the eastern tip of Japan. In July and August one storm crosses Luzon, another crosses Formosa, two others reach the Yellow Sea, and the remaining two pass along the western side of Japan. In September and October there

are on the average eight storms; these follow diverse tracks and penetrate all major parts of the region except northern China. In the average

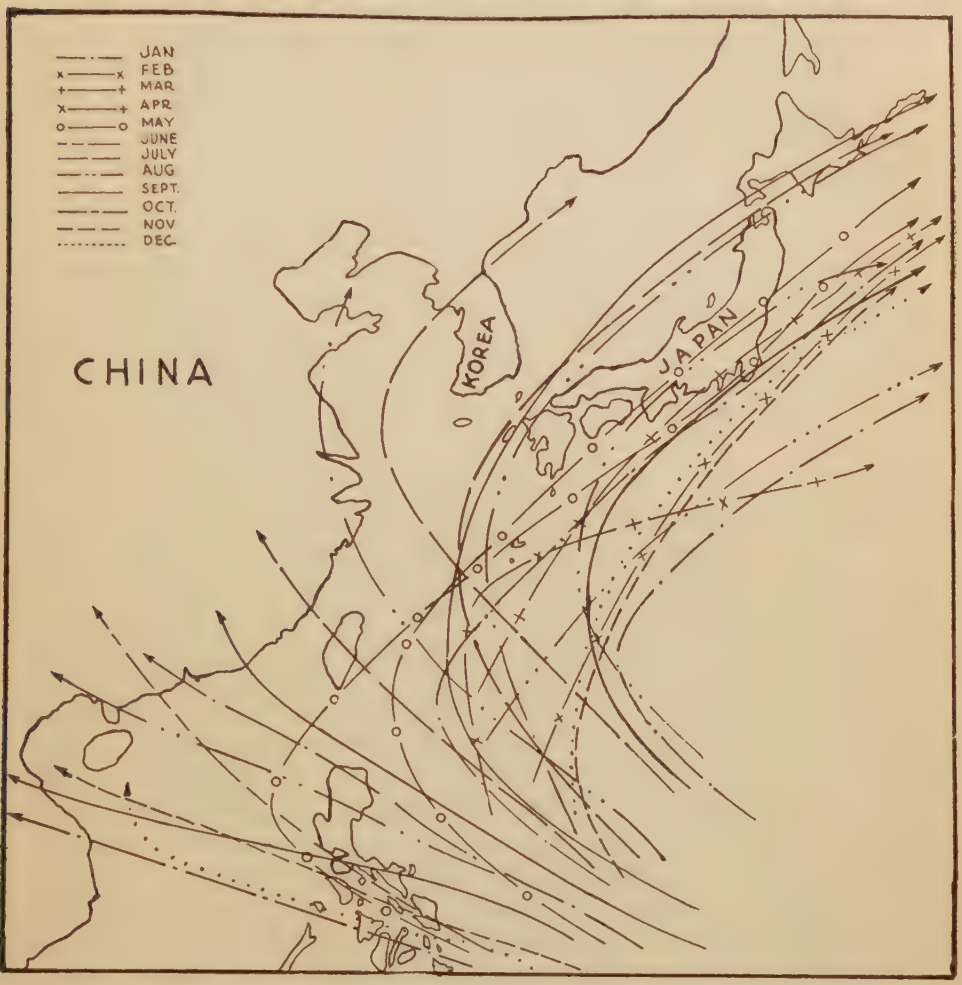


FIGURE 9.—Map showing typhoons of an average year, month by month. Each track represents the average of twenty-five tracks of Froc's Atlas.

November and December, two storms cross the southern Philippines, and two move off northeastward well to the east of Japan.

This seasonal change in the course of typhoons is strikingly illustrated in another way by twelve "Summary Maps" issued by Froc (65), which indicate that no typhoons normally reach the Asiatic coast in January, February, or March, and the only region crossed or closely approached by typhoons in April and December is far south, in Anam or French

Indo-China. In May and November the coastal area of danger has expanded northward to latitude 20°. On the other hand, from July 1, to October, no part of the Asiatic coast, except the extreme south, is free from danger from typhoons. In October the coast north of latitude 30° is again free from grave danger, while Anam is again threatened. In the Philippines, Luzon is very seldom approached by typhoons in January, February, or March, while the danger is considerable in the southern islands during every month except August.

Although most typhoons are fairly normal in their movements, there are on the average two or three a year which follow aberrant tracks along part of their tropical courses. Hence, it is quite essential for navigators to understand that wide departures from the normal are to be expected. In order that the character of the departures may be readily apparent, a chart (fig. 10) has been constructed. The monthly distribution of the 57 aberrant storms included in figure 10 is shown in Table 22.

TABLE 22. MONTHLY DISTRIBUTION OF 57 TYPHOONS WHICH FOLLOWED UNUSUAL PATHS

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Monthly No.....	2	....	....	1	4	1	11	6	5	7	11	8
Per Cent (approximate)....	4	....	....	2	7	2	20	11	9	12	20	14

When the distribution is compared with the distribution of typhoons in general (Table 10 and fig. 9), it appears that abnormal typhoons have a less symmetrical monthly distribution than normal typhoons and that, although they are rare or lacking in February, March, and April, when normal typhoons are rarest, they are not most abundant when typhoons are most frequent. Only 20 per cent of the abnormal storms occurred in August and September, in contrast with 34 per cent of the normal storms. On the other hand, although only 14 per cent of all typhoons occur in November and December, 34 per cent of the aberrant storms occur in those two months. Many of the aberrant storms of November and December, however, are remarkable rather for the low latitude of their occurrence than for their abnormal direction of progression. Nearly 36 per cent of the typhoons occurring within eight degrees of the Equator develop in November and December. (See Table 22.) Additional facts concerning these aberrant storms are presented in Table 23.

From Table 23 it appears that there is slight likelihood that a typhoon occurring in the period February to May will move in a southerly direction. Indeed, south of latitude 15° N. the chance of this particular

abnormality remains almost negligible until October, but is considerable in November. The likelihood that a typhoon in latitudes below 20° N.

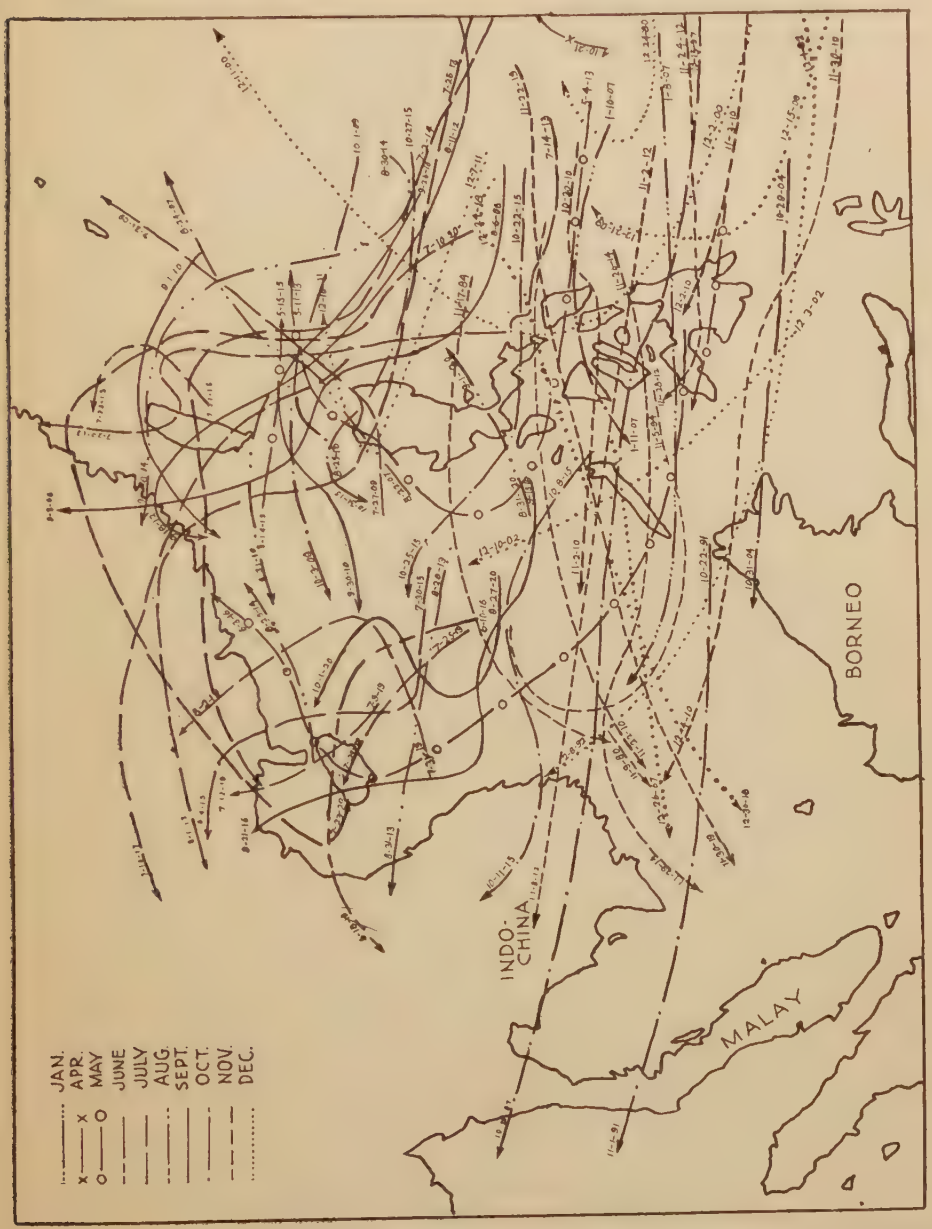


FIGURE 10.—Map showing tracks of typhoons which followed abnormal courses. (Compiled from maps issued by the observatories of Manila, Hongkong, Zikawei, Kobe and Tokyo, and from Pilot charts.)

will move in an easterly direction rather than in a westerly or northerly direction, appears to be greatest in December, July, and August. The

prospect of a sinuous course, perhaps with a loop, seems appreciable only in the period July to November, but in those months so many typhoons depart from a straight course, or a simple curve, that the possibilities of abnormal change of direction are considerable north of latitude 15° N.

TABLE 23. ABERRANT TYPHOONS CLASSIFIED BY MONTH AND DIRECTION OF MOVEMENT

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Typhoons which moved easterly, below 20 N. (some without first recurving)	....	....	....	1	1	....	2	2	1	....	1	3	11
Typhoons which moved south of due west within 15 S., north of 15 N.	1	....	....	....	....	....	....	....	....	1	5	2	9
Typhoons which moved south from north of 15 N.	....	....	....	....	....	1	2	2	3	2	....	....	10
Typhoon tracks forming sinuous curves or loops in low latitudes	....	....	....	....	....	....	5	2	4	3	2	....	16

The abnormal typhoons charted in figure 10 are of great scientific interest, for as with many other natural phenomena the abnormal may reveal more than the normal concerning fundamental causes and relations. The irregular movements of typhoons forcibly suggest the importance of irregular changes in atmospheric pressure. The importance of such changes has been recognized by a few meteorologists, but most students have relied on the influence of regular rather than irregular forces to explain storm movements. For example, topographic features, prevailing wind directions, and Ferrel's law of deflection to the right in the Northern Hemisphere have been called upon to explain the recurve of tropical cyclones. All three of these forces combined appear totally inadequate to explain many of the curves shown in figure 10. Many storm tracks fail to show any response to Ferrel's law, and many appear to ignore the prevailing winds. Comparison of the winds in January and February, and July and August, as shown by Köppen (109), with the tracks of typhoons, reveals the fact that many typhoons advance towards the prevailing surface wind. Topographic features likewise afford an inadequate explanation, for most of the curves take place far from land. A casual relation of the recurve to the position of the so-called permanent oceanic high pressure area has been suggested by Vines (191). But it is obvious from figure 10 that however much the average position of the recurve may be thus affected, many exceptions occur. Many irregularities in pres-

sure conditions, believed responsible for the irregular course of many typhoons are due to other cyclones. But many irregularities also are difficult to explain, as for example those which appear when no other cyclone is known to be near; but that does not make such irregularities of pressure the less potent. (See p. 96.)

TABLE 24. AVERAGE LOCATION OF RECURVE OF TYPHOONS, BY MONTHS AND REGIONS

Month	China Sea	N. China Sea	Formosa	Yellow Sea	Near Japan
June	15 N., 112 E.	.....	27 N., 121 E.	29 N., 123 E.	29 N., 127 E.
July	21 N., 107 E.	21 N., 117 E.	27 N., 119 E.	29 N., 123 E.	27 N., 129 E.
Aug.	.....	22 N., 118 E.	26 N., 119 E.	33 N., 123 E.	26 N., 127 E.
Sept.	20 N., 119 E.	24 N., 116 E.	.....	.....	24 N., 129 E.
Oct.	16 N., 120 E.	18 N., 120 E.	16 N., 119 E.	.....	37 N., 136 E.
Year	17 N., 115 E.	21 N., 118 E.	24 N., 119 E.	31 N., 123 E.	27 N., 129 E.

The omission of figures in the table indicates that no storms normally recurve in the area and the month specified.

COURSES OF TROPICAL CYCLONES OF THE SOUTHEAST NORTH PACIFIC

Figure 11 includes the tracks of tropical cyclones off the west coast of Mexico and Central America. Because of the relative scarcity of reports from this region, many of the published courses have been plotted from the observations of a single reporting ship and are very incomplete. The shortness of many of the tracks also suggests incompleteness. Several of the recent storm tracks plotted by Hurd (96) are about 20 degrees long, whereas many of the earlier tracks are shown as less than 10 degrees long. Correspondingly, the tracks recently reported are less simple, less nearly straight, and less "normal" than are most of those of early date. Some storm tracks near Hawaii are shown in figure 12.

From the evidence at hand, it appears that most of the tropical cyclones of the eastern North Pacific travel northwest on fairly straight courses. A considerable number, however, travel north, especially near the coast, and a number recurve and pass eastward over the land. Three are shown crossing to the Gulf of Mexico, one in October, 1923. One of these reached Florida, and the other two continued for many miles into the southern states as severe storms. Another storm, occurring in September, 1921, was traced up the west coast of Mexico and thence across the United States to Newfoundland. Day (46) reports that two of the storms of 1922 originated in the Caribbean Sea and crossed to the Pacific. Several storms moved almost due west as far as traced. Three moved somewhat south of west, an abnormal course; especially conspicuous is

the storm of September, 1899, which moved almost due southwest for 15 degrees (two days). Two of the thirteen tracks plotted by Hurd (95) are somewhat sinuous, and a third recurves to the left for several degrees.

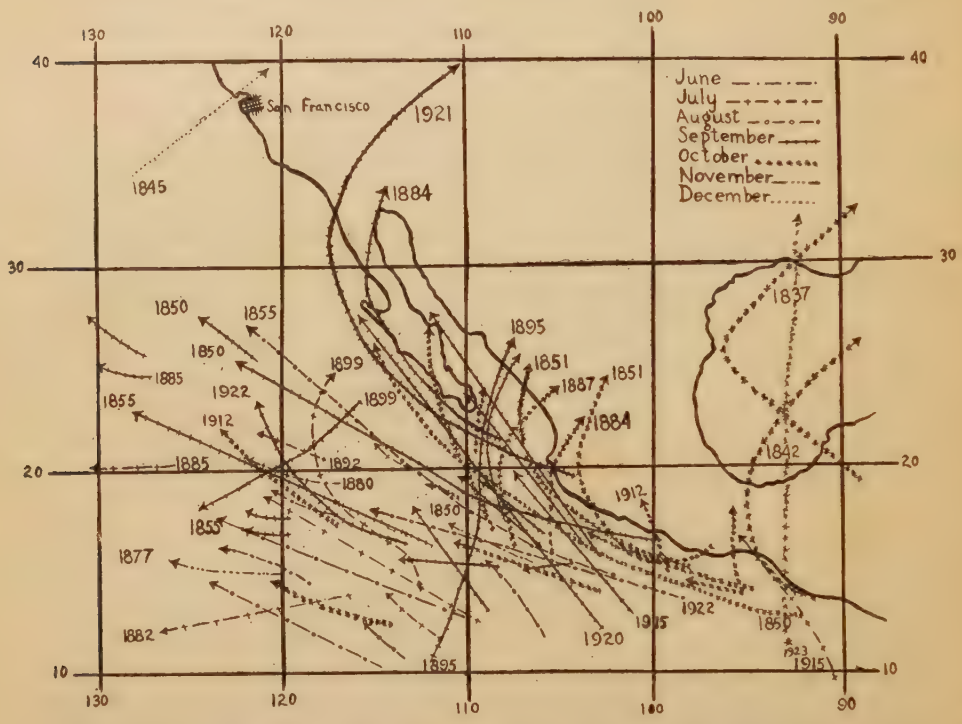


FIGURE 11.—Map showing tracks of tropical cyclones in the eastern North Pacific. (After Redfield, Hurd, Deutsche Seewarte, Segelhandbuch, and United States Pilot charts.)

STORM TRACKS IN THE WESTERN SOUTH PACIFIC

Figure 13 shows the approximate courses, so far as known, of hurricanes in the western South Pacific. It indicates that most of the storms move south or southwest while within 20 degrees of the Equator, and south-southeast or southeast in higher latitudes. However, a detailed study of the tracks crossing Fiji (figs. 14, 15) and New Caledonia, shows that a large percentage of the storms moved westward or eastward across these representative island groups. The same is true for storms along the eastern coast of Australia. Hence, the straightness and simplicity of most of the published tracks of South Pacific hurricanes probably reflects inadequate information. Two abnormal tracks merit special mention. The storm of February, 1878, crossing New Caledonia, recurved towards

the west (right) instead of towards the east, and the storm of January, 1922, described a loop south of New Caledonia, and also recurved to the right.

Many of the storm tracks of the western South Pacific have no well-

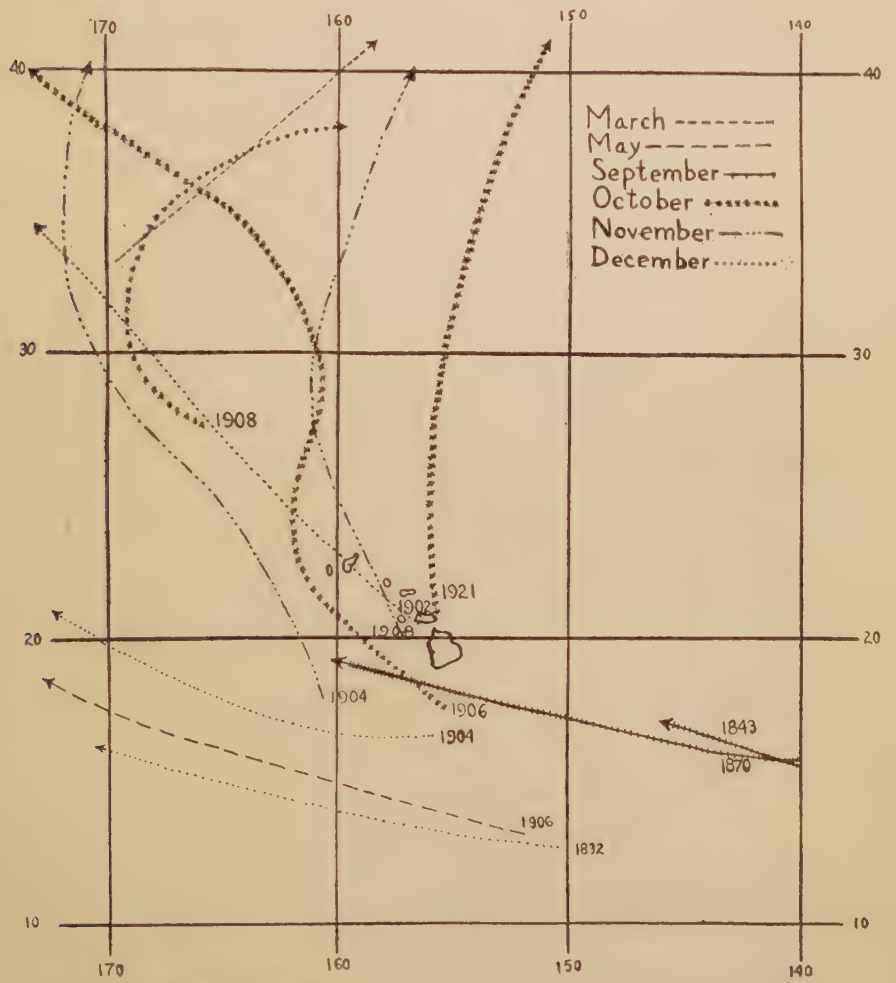


FIGURE 12.—Map showing tracks of tropical cyclones near Hawaii, 140°-175° W. (Sources as for figure 11.)

defined point of recurve, being nearly straight or else parabolic. Knipping (106), however, has recorded the average latitude of recurve for 20 hurricanes. His figures are: December, 2 storms, average latitude of recurve 16.7° S.; January, 5 storms, 18.5° S.; February, 3 storms, 19.3° S., making the average position of recurve for these 10 storms, 18.4° S. The

average latitude of recurve for 10 storms in March is 20.2° S. It is interesting to note a slight progressive increase in latitude from December to March.

TRACKS OF AUSTRALIAN HURRICANES

The tracks of representative tropical cyclones over Australia are shown in figure 16, based on a study of the daily weather maps. Tracks of about

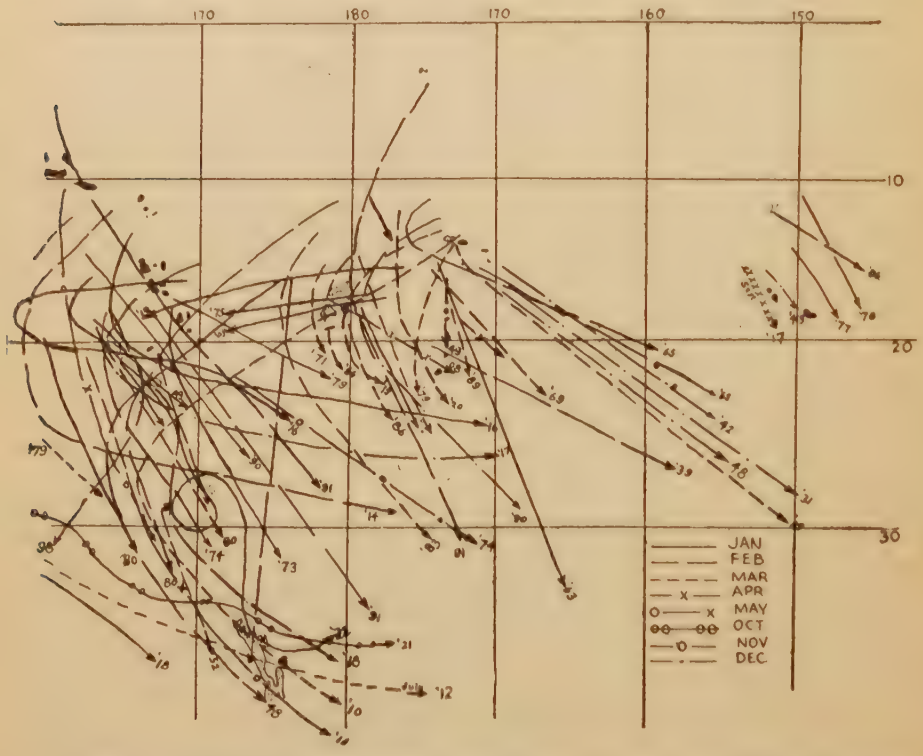


FIGURE 13.—Chart of representative cyclone tracks in the western South Pacific. 160° E.-145° W. (From Knipping with additions.)

twenty storms were traced by Hodge (80). The remaining tracks were traced by me, with the help of Mr. Hodge. The task was made easy by having access to the reductions of the daily weather maps for 1892-1922, made by Mr. E. T. Quayle of the Commonwealth Weather Bureau.

A study of these storm tracks reveals the following features:

1. Although most of the storms move southward into higher latitudes, they follow no prescribed paths, except perhaps across the southwestern part of the continent, from Onslow to the Bight and on toward Tasmania.

Instead, some storms move southwest, others southeast, some even northward for a distance. Many change their direction of progression several times. The larger the number of tracks studied, the more evident it becomes that the storms are influenced by changing atmospheric conditions, rather than by the unchanging relief features.

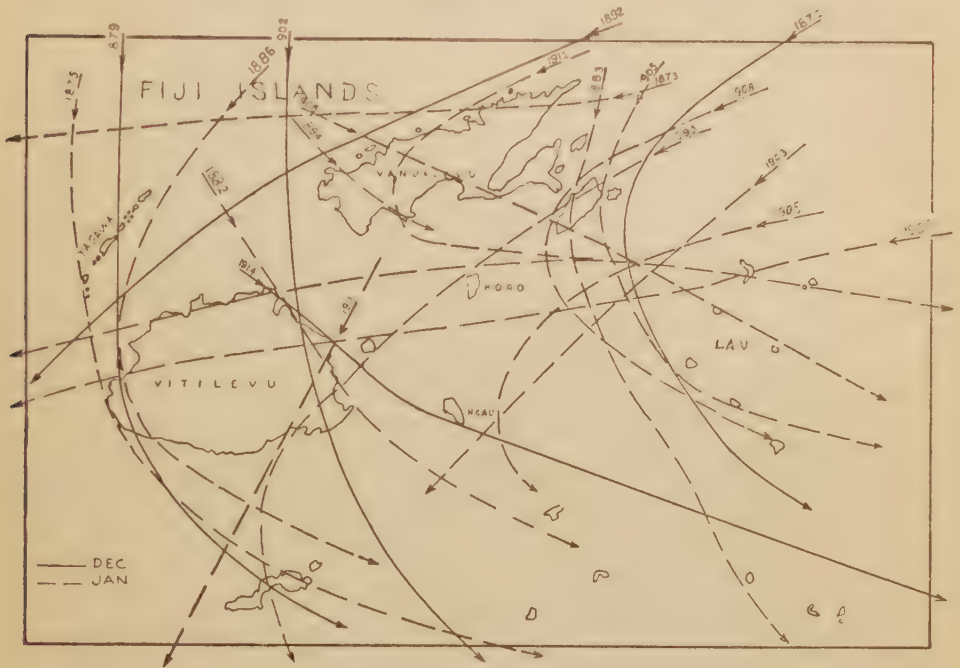


FIGURE 14.—Map showing the approximate tracks of tropical cyclones which crossed the Fiji Islands in December and January. (From Knipping, Holmes and Knowles, with additions heretofore unpublished, traced from the records.)

2. Although all portions of Australia are crossed by tropical cyclones, notable destruction upon the land has been almost lacking in the extreme southern parts of the continent. The region between Melbourne and Sydney and the extreme southwestern part of the continent appear to be especially fortunate in this respect.

3. About one-fourth of the storms recurve rather sharply, their tracks forming parabolas: one-fourth recurve less sharply, their tracks forming hyperbolas. For almost one-fourth, the segment of the track traced might be one leg of a hyperbola. The remaining fourth of the tracks show no sign of curving on a regular course, being either almost straight, or curving irregularly.

4. Where recurving is evident, the apex of the recurve is generally

in tropical latitudes. In other words, nearly all storms located to the poleward of the Tropics move eastward or southwestward, while in the tropical portion of the continent about as many move westward as eastward or southward.

5. The storms of the main hurricane season, December to April, are much more likely to recurve on a parabolic or hyperbolic course than

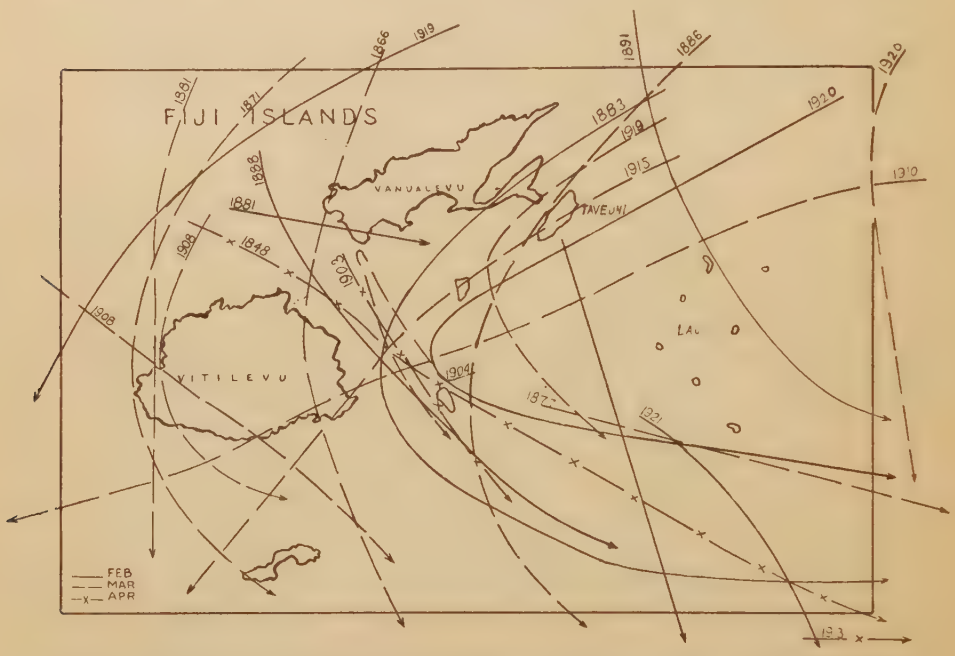


FIGURE 15.—Map showing the approximate tracks of certain tropical cyclones which crossed the Fiji Islands in February, March and April. (Sources as for figure 14.)

are the storms of the other months. Indeed, the storms of May to November have a strong tendency to follow rather straight courses.

6. There seems to be a slight tendency for the storms which occur late in the year to be destructive further south than are those occurring in January to April. However, in Timor April appears to be especially subject to hurricanes, and in December several severe storms have occurred within 20 degrees of the Equator in Western Australia, as well as beyond the Tropics near latitude 30° S. in Queensland.

7. As to origin, a large part of the storms approach the coast of tropical Australia from the east; a considerable number apparently originate to the north or northeast of the continent, and move southward along the coast of Western Australia, or else move inland; some storms appear

to originate in the interior, especially over the Gulf of Carpentaria, and storms move south, southeast, southwest, or west. Many storms disappear in the interior of the continent.

QUEENSLAND HURRICANES

Most of the hurricanes which affect Queensland come from the east, approaching the coast somewhere between Townsville and Cooktown.

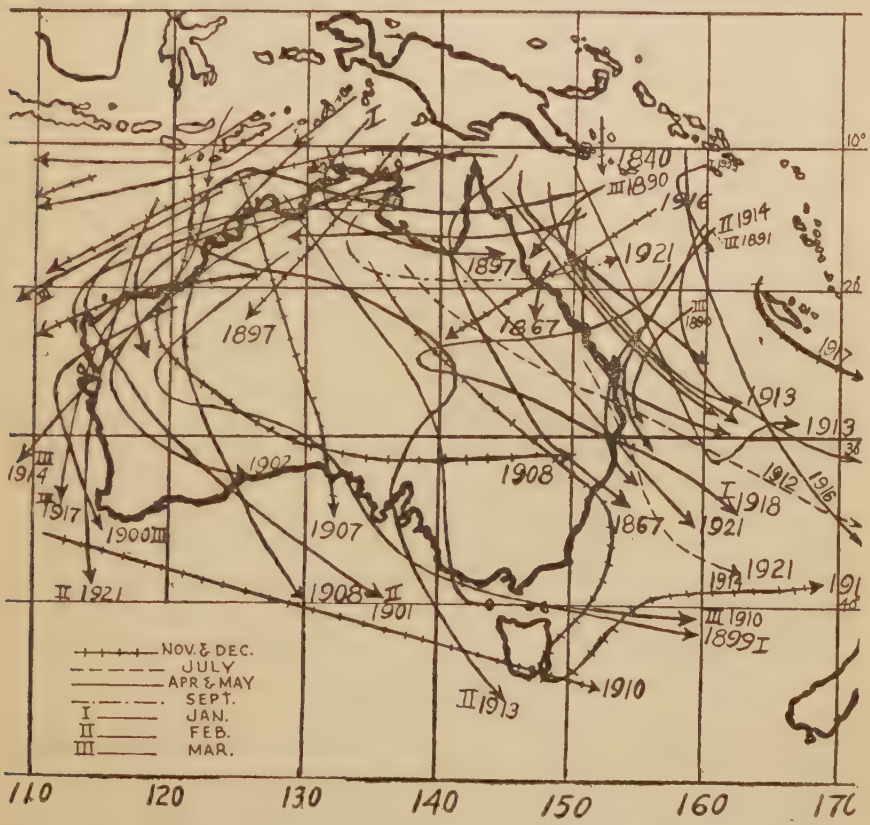


FIGURE 16.—Map showing tracks of representative Australian hurricanes. (Traced from Australian Daily Weather Maps.)

Many recurve near the coast, passing southward nearly to Brisbane, and then moving off to the east-southeast. Others recurve some distance east of the coast, for example, near the Great Barrier Reef, and pass southward and then eastward without doing much damage to the coast. Still others, especially those which strike the more northern portions of the York Peninsula, pass inland, some crossing the continent to Western Australia, and others recurving in the interior and passing

out to sea again across southern Queensland. Many hurricanes lose force shortly after coming onto the land. Some strengthen again notably upon reaching the coast after their journey across the land. The Queensland coast is affected also by storms which have developed, or at least are first recorded in the interior of the continent, and which then move east-southeast across the southern part of the state. Perhaps more numerous meteorological stations would show that storms of this type, instead of developing in the interior, as they seem to do, enter the interior from the east or north in sparsely settled districts and are not observed until they have recurved and are passing out toward the southeast.

WESTERN AUSTRALIA HURRICANES

The hurricanes which affect Western Australia come chiefly from two directions: east across the Northern Territory, and from the north or northwest. Of the north or northwest storms a number develop in the Cambridge Gulf, or in the Arafura Sea, south of Timor, move southwestward, recurve not far west of Australia, and come onto the Australian coast traveling from the west-northwest. The area between Broome and Onslow is hit most frequently by such storms. Some change their direction after reaching the coast and pass southward along it; others continue into the interior, where they often disappear. Some, however, proceed straight on across the continent, and reach the southern coast near the eastern side of the Bight. Adelaide has been affected several times by such storms; in 1916, quite severely. Of the storms which reach western Australia from the east, some appear to have developed in the northern interior, while others are known to have come across northern Queensland. Indeed, several recent storms traveled from east of Queensland across Northern Territory, then far southward along the western coast of Australia, next across the southwestern corner of the continent, and thence eastward through Bass Strait to New Zealand, a total distance of more than 9,000 miles. Although few such storms are destructive over much of the distance, some of them show little evidence of marked decrease in intensity. The portion of Western Australia which is most often severely damaged by hurricanes, lies between Geralton and Broome. Hurricanes are rare at Perth. Many, however, cross the southwestern corner of the continent, passing east of Perth and affecting the Coolgardie region.

Most of the hurricanes which affect the Northern Territory come from the east, although about one-fifth come from the west and appear to be storms which recurved to the northwest of the continent, perhaps having developed in the Arafura Sea.

VELOCITY, SIZE, DURATION AND INTENSITY OF TROPICAL CYCLONES

VELOCITY OF STORMS

The speed of travel of tropical cyclones differs from storm to storm and also varies during the life of each storm. It ranges from one mile to more than fifty miles an hour. The higher velocities are commonly observed near the margin of the tropics.

During their incipiency, tropical cyclones often progress slowly. After they commence to move, they commonly gain speed progressively. Some, however, slow down again before recurving and many slow down while recurving. After they have recurved and are moving eastward, nearly all of them gain speed again.

A certain amount of seasonal variation in velocity is indicated in Froc's tables of velocities (65), which indicate that the average velocity is greater in the main storm season than in other months, although extreme speeds are not limited to this period.

"Stationary cyclones" were formerly thought to occur, but the studies of recent years indicate that, although many storms move very slowly at first, and sometimes while recurving, none are entirely stationary. Some oscillate back and forth, especially while forming, but also during recurving or at other times. Some describe loops, which, at a considerable distance, may give the impression that the storm is stationary.

The unusually swift storms, those progressing more than 300 miles a day in the Tropics, or more than 600 miles a day after recurving, apparently are related to a peculiar combination of changing air pressure conditions. Especially swift storms either are moving into an area of unusual low pressure, or are being crowded forward by advancing areas of abnormally high pressure.

Many notable irregular changes in velocity of progression occur, especially when a number of tropical cyclones are present simultaneously in the same general region. The normal advance of one storm may be interfered with by another, or by the higher pressure that generally prevails in the rear of a cyclone. Hence, a storm may be slowed up or diverted out of the normal course until the preceding disturbance is sufficiently out of the way to permit a more normal advance. In the western North Pacific, where cyclonic disturbances from the continent of Asia, as well as typhoons, are frequent, irregularities in the velocity of both types are especially common.

Table 25, which is based on Table I and II of Froc's Atlas, gives the

mean and extreme speeds in miles an hour and the point of the compass toward which storms are moving. According to this table, the lowest mean speed for the storms of any month is six miles an hour, or 150 miles a day in March, in the southern part of the China Sea, and seven miles an hour in April, near Japan. The average mean speed in the China Sea and elsewhere is about 240 miles a day for storms moving northwestward, and about 450 miles for storms moving northeastward. The highest mean speed for storms moving northwestward near Formosa is 13 miles an hour in October. Near Japan, however, such storms have a mean speed of 13 miles an hour in February, and more than 15 miles in October. Extreme speeds shown in Table 25 increase with latitude from 17 miles an hour in September in the south China Sea to 22 miles an hour for a storm moving northwestward near Formosa in September, and 34 miles an hour for a storm moving northeast near Formosa in September. During three months, extremes of 40 or more miles an hour for storms moving northeastward near Japan are recorded; the fastest storm traveling 52 miles an hour in September.

TABLE 25. VELOCITY OF TYPHOONS IN MILES AN HOUR, BY MONTHS AND REGIONS

Month		China Sea North to Lat. 18°		China Sea Lat. 18-23°		Formosa to Lat. 30°		Yellow Sea		Near Japan		Open Pacific	
		NW[a]	NE[b]	NW	NE	NW	NE	NW	NE	NW	NE	NW	NE
Jan.	Mean	11.0	....b	....	....	....	....	....	....	....	23.4	....	18.8
	Extreme	14	....	....	....	....	....	....	....	....	30	....	31
Feb.	Mean	9.0	....	....	....	....	....	....	....	13.3	16.0	....	21.6
	Extreme	9	....	....	....	....	....	....	....	18	18	....	40
Mar.	Mean	6.0	....	....	....	....	....	....	....	10.0	21.5	11.0	21.6
	Extreme	6	....	....	....	....	....	....	....	....	30	11	30
Apr.	Mean	9.7	....	....	....	....	....	....	....	7.5	20.7	13.7	26
	Extreme	12	....	....	....	....	....	....	....	8	28	10	43
May	Mean	11.3	....	....	....	....	....	....	....	9.7	19.2	8.9	16.9
	Extreme	16	....	10	....	....	....	....	....	13	25	16	28
June	Mean	10.1	....	10.0	....	11.5	18.7	....	....	....	14.0	9.0	17.1
	Extreme	15	....	12	....	16	23	....	....	....	14	10	32
July	Mean	10.8	....	8.7	25	10.3	19.8	11.4	18.6	11.9	18.9	11.3	18.8
	Extreme	14	....	13	....	12	23	15	26	16	25	15	28
Aug.	Mean	10.7	....	10.2	12	11.1	20.2	12.9	18.7	11.1	18.9	13.2	18.0
	Extreme	14	....	16	12	22	26	20	27	21	40	17	25
Sept.	Mean	11.0	....	10.8	....	12.1	22.4	10.6	21.4	11.9	22.8	10.0	18.2
	Extreme	17	....	18	....	17	34	16	25	20	52	15	38
Oct.	Mean	10.6	....	9.9	10	13.5	....	....	21.0	11.9	21.5	12.5	17.0
	Extreme	16	....	12	10	15	....	....	21	20	39	20	25
Nov.	Mean	10.1	....	8.0	8	....	....	....	....	16.3	22.6	8.2	16.8
	Extreme	16	....	8	8	....	....	....	....	15	40	11	25
Dec.	Mean	11.8	....	12.0	....	....	....	....	....	11.0	25.0	12.0	19.7
	Extreme	16	....	12	....	....	....	....	....	12	38	12	28
Mean		10.2	....	10.1	19	11.7	20.3	11.6	19.9	11.5	20.4	11.0	19.2

a—NW and NE indicates the direction in which a typhoon is moving.
b—The absence of figures in this table indicates that no storms of this type normally occur in this month.

East of the Philippines, greater extreme velocity has been recorded than that given by Froc for the China sea; namely, 17 miles an hour south of latitude 20° N. and 18 miles an hour north of latitude 20° N. The extreme velocity recorded for very low latitudes appears to be that of a typhoon recorded by Algué (4), which traveled at the rate of 21 miles an hour for the distance of eleven degrees, from south of Yap due west to Mindanao, which it struck in latitude 7° N.

The storms in the eastern North Pacific differ in velocity much as do those of other regions. Some move slowly, more slowly than any Redfield (150) reported for the Atlantic, and many others travel at the average speed of typhoons. Several storms recently charted by Hurd (95) traveled for one day at the rate of 350 miles a day, while within 20 degrees of the Equator. The storm of July 4-6, 1915, traveled 17 miles an hour, or more than 400 miles a day, while in latitudes 9° to 13° N. Very few typhoons travel so fast in such low latitudes. (See Table 25.) The average speed of the thirteen storms charted by Hurd (95) was 241 miles a day in latitudes lower than 20 degrees, and 252 miles a day in latitudes 20° to 25° N. The slowest movement was about 130 miles a day. Thus they had an average velocity very close to that of typhoons before their recurve.

Information concerning the progression of storms near Fiji and elsewhere in the South Pacific indicates a variability and range similar to that found in the North Pacific.

A study of the storm tracks of figure 16 indicates that most Australian hurricanes gain speed as they progress, traveling about twice as rapidly, on the average, in the sub-tropical portions of their course as in the tropical portions. In the Tropics, their average speed is about 200 miles a day, and in latitudes above 30 degrees their average is more than 400 miles a day. The range in speed is high, however, some storms in tropical northern Australia traveling 500 miles a day, and a few storms south of latitude 30° S. traveling 100 miles or less a day. The storms which occur out of the main hurricane season, May to November, appear to have a somewhat higher average speed than those of the main season, December to April. This is the reverse of the relation reported by Froc (65) in respect to typhoons along the China coast, but in accord with his data for typhoons passing Japan, and also for those in the Pacific southeast of Japan.

SIZE OF STORMS

Although on the average a belt 300 to 400 miles wide experiences gales when a tropical cyclone passes, the zone may be much smaller or vastly larger, for tropical cyclones vary greatly in size. The smallest ones are

less than 50 miles in diameter; the largest more than 1000 miles across. Some attain diameters of more than 2000 miles after leaving the Tropics. The region of greatest destructiveness is the strip usually from 10 to 30 miles wide over which the "eye" of the storm passes, although the adjacent country on either side of this zone commonly suffers almost as much. For some storms the damage done by waves and wind is limited to a belt 30 to 50 miles wide, although torrential rains may affect a wider damage.

While within the Tropics, the average storm is perhaps 300 miles in diameter. Since the storm area normally increases in size as it advances into higher latitudes, most tropical cyclones that reach mid-latitudes are 500 miles across, or even larger.

There is also some regional variation. Tropical cyclones of the eastern North Pacific and of the western South Pacific appear to be smaller, on the average, than typhoons or West Indian hurricanes. In Australia and the western South Pacific, however, an exceptional storm strongly affects a zone more than 1500 miles across.

Some seasonal variation in average size of storms has been noted. Those of the main storm season are on the average larger than those of the less stormy months.

Tropical cyclones that are destructive over a very wide belt are sufficiently few in number to lead to the popular belief that they occur somewhat periodically at an interval of several years or a generation, but too few remarkable storms have been recorded to permit safe generalizations as to their periodicity.

DURATION OF STORMS

With reference to duration, tropical cyclones may be classified as three types: (a) the short-lived storm, lasting only a day or two; (b) the common storm, lasting from three to six days; (c) the long-lived storm, lasting more than a week. Some of the long-lived storms have been followed for more than three weeks, but during their course in mid-latitudes were indistinguishable from extra-tropical lows.

Many typhoons have been traced from near the Philippines to the coast of British Columbia, and a number have been followed across North America and the North Atlantic to Europe. One such storm mentioned by Shaw (161) lasted 63 days. Others have been traced from east of the Philippines across the Malay Peninsula to the Bay of Bengal. One of these in October, 1897, traveled approximately 4500 miles in the nine days of its recorded course. Another in October-November, 1891, traced by Algué (7), took 15 days to cover a similar distance. A tropical cyclone,

that developed on September 25, 1912, in latitude 16° N., off the western coast of Mexico, was traced across the United States and the Atlantic, almost to the British Islands. This journey required 14 days.

A number of tropical cyclones have been traced from east of Queensland, across northern and western Australia and thence on to New Zealand, a distance of about 9000 miles. Some of them showed no marked decrease in intensity, and there is no reason to suppose that they died out immediately after passing eastward out of the area covered by the Australian weather map.

The distance that tropical cyclones travel is illustrated by the courses of some West Indian hurricanes. A number of these have been traced by Mitchell (128) from the west coast of Africa to the West Indies, and thence north and east to Europe. Some have been traced across Europe into Asia, a total distance of more than 12,000 miles.

The tendency for cyclonic storms to weaken markedly in areas of high pressure often causes them to be lost sight of before they have actually disappeared. Both Froc and Okada told me that they had traced typhoons far into Asia, and, after all ordinary signs of them had vanished except a slightly lower pressure, had seen them increase greatly in force upon reaching the sea again. They expressed the opinion that when sufficient pressure data are available, a close study will prove that most typhoons give rise to what are generally known as extra-tropical cyclones.

INTENSITY OF STORMS

Storm intensity may be measured by several different standards. Coronas (38) uses the pressure at the center and classifies all typhoons with minima of less than 720 mm. (28.35 inches) as "very remarkable"; those with minima of 720-742 mm. (28.35-29.2 inches) as "remarkable"; and those with minima of higher than 742 mm. (29.2 inches) as "ordinary." Of 60 typhoons affecting the Philippines in the 16 years, 1903 to 1918, inclusive, 14 were classed as "very remarkable," among them five with observed minima of less than 700 mm. (27.56 inches, 933.3 millibars). The date, the location, and the pressure of these five storms are as follows:

1905, Sept. 25; Samar; 690.1 mm. (27.2 inches, 921.3 mb.).
1908, Sept. 23; Borongan; 699. mm. (27.5 inches, 931.9 mb.).
1911 Aug. 26; Basco; 690. mm. (27.2 inches, 919.9 mb.).
1912, Nov. 24; Tucloban; 693. mm. (27.3 inches, 923.9 mb.).
1913, Aug. 17; Babuyanes; 683.2 mm. (26.89 inches, 910.6 mb.).

Minima of less than 27.56 inches (700 mm.) have characterized tropical cyclones in other parts of the Pacific. For example, the Fiji hurricane of January 28, 1912, had a pressure of 27.15 inches (919.4 mb.) at Dreketi,

27.25 inches at Bua, of 27.30 inches at Loma Loma, and 27.40 inches at Bavatu. A number of Australian hurricanes also have had recorded pressures of less than 27.56 inches; for example, the Mackay storm, June 20, 1918 (27.5 inches, 931 mb.), and the Cossack storm of January 7, 1881 (27.0 inches, 914.3 mb.). But pressures below 28 inches (711.2 mm., 948.2 mb.) are not essential features of destructive storms. Indeed, many of the most destructive storms have had pressures above 29 inches (736.6 mm., 999 mb.). Damage resulting from hurricanes depends largely on factors other than the pressure at the center.

A common classification of storm intensities is based upon the strength of the wind. Tropical cyclones which are accompanied by winds of hurricane force (75 miles an hour, 34 meters a second, or more) are "real storms"; and those in which the wind is a "whole gale" (40 to 75 miles an hour) are "moderate storms," and those in which the wind is of less intensity are "disturbances." The area they affect has been used as a basis of classification of storms. Storms creating winds of hurricane or gale force over a wide and long belt are considered "especially intense," and those affecting a small area are often ignored unless they happen to demolish a town or sink a steamer. Three other bases of classification are sometimes used: the amount of destruction, the size of the waves, and the amount of rainfall.

The amount of destruction depends far more upon the course that the storm takes than upon its intensity. A small storm with winds of only gale force may do more damage if it strikes a large city on a low coast than a more severe storm crossing an area of water or of sparse population. The size of the waves and swells bears a closer relation to the speed of travel of a tropical cyclone than to its intensity. A stronger swell may be developed by a slowly moving storm than by a swiftly moving storm of even greater severity.

As to rainfall, although all storms are accompanied by heavy rains, some far exceed the average in this respect. The torrential downpours are often the chief cause of damage. Hence, a classification based on damage done is likely to consider rainfall as well as wind velocity.

THE ORIGIN OF TROPICAL CYCLONES

Information regarding the place, the time, and the mode of origin of tropical cyclones is inadequate. Still less is known about the fundamental causes. More careful observations of temperatures and air movements at various altitudes, both within the disturbance and at varying distances from it, are necessary before several problems can be solved.

PLACE OF ORIGIN

Most tropical cyclones originate over the sea, toward the center or the western sides of the oceans, and in the doldrum belt when it is relatively far from the Equator. A considerable number appear to develop over the Australian continent, chiefly, however, over the Gulf of Carpentaria (p. 55). Elsewhere, the development of certain storms is so closely related to islands that Vines (190) and other writers have held the erroneous belief that islands are essential to their origin.

A somewhat similar erroneous belief is that if an island is not present, there must be a large area covered with floating seaweed, such as is found in the Sargasso Sea to the east of the West Indies, simulating land conditions; or, at least an area of shallow water. Still other students believe that while no one of these three conditions is essential, stagnant water is necessary. Each of these conditions favors an abnormal local warming of the surface air, which is assumed to be conducive to the origin of the storm. But that abnormal local warming of the surface air is not absolutely required is shown by the fact that many storms originate far east of the warmest part of the ocean in their latitudes, which is towards the western sides of the oceans. Indeed, the evidence of recent years suggests that perhaps most storms originate well out in the oceans, and many originate toward their eastern sides (pp. 47, 58). The greater storm frequency toward the western side may very well be caused by the movement of many storms from the central portion to the western portion of the ocean before recurving. Likewise, many storms originate poleward of the doldrums, especially during the winter and spring months, when neither the water nor the surface air is so warm in latitude 20° N., as it is nearer the Equator. Additional evidence against the importance of a local area of exceptionally warm air is the fact that in some regions storms rarely originate over islands. For example, Mitchell (128) reports that a fuller study of the West Indian hurricanes charted by Fassig as being first observed over islands, has shown that all of them originated over the sea to the eastward. Indeed, Mitchell has written me: "If there

is anything that my study has firmly established it is that West Indian hurricanes always originate over the sea." Yet, meteorological observations and the presence of the sea breeze proves that the air is often warmer by day just above an island than it is over the adjacent sea.

Tropical cyclones may form over the sea rather than over islands because of the greater uniformity of conditions over water than over land. Such local differences in heating, as are common on land, give rise to local convection currents such as create cumulus clouds or thunderstorms. This type of convection appears to be unfavorable to the development of so widespread a disturbance as a tropical cyclone. Uniform expansion of the lower air over a rather large area appears to be essential to the formation of tropical cyclones (p. 91).

The place of origin is related to the wind systems as well as to land and water. Most tropical cyclones originate in the doldrum belt when it is a few degrees away from the Equator. The storms of the Arabian Sea which develop chiefly in the spring and fall during the change from winter monsoon to summer monsoon, and vice versa, are a notable exception. A less local exception is afforded by the occasional storms of winter and spring, when the doldrum belt is on the opposite side of the Equator. The storms of this type are by no means so rare as has been generally supposed, and the fact that few are as severe as the average storm of the late summer apparently is due rather to encountering unfavorable conditions after development than to an abnormal origin.

The considerable number of storms that apparently originate near the margins of the Tropics, led Redfield (150, p. 20) to believe that the normal place of origin is near the poleward margin of the belt of trades, rather than at the equatorward margin, as is now generally believed. Still other storms originate within the belt of the trades, but during lulls in the blowing of the trade winds. Many others originate in the belt between opposed winds. The belt of doldrums is such a place, as are also some places between the trades and monsoons, between cyclonic disturbances, and between anticyclones. Newnham (135) reports that many tropical cyclones develop in the South Indian Ocean in V-shaped areas of lower pressure between areas of higher pressure. "Indeed, if such a depression forms near Mauritius from December to May, sometimes three to five tropical cyclones form in rapid succession."

Although many tropical cyclones develop between opposing winds, not all types of opposing winds are provided favorable conditions. Sir Napier Shaw (164) states, "When a westerly current (in the Northern Hemisphere) has an easterly current upon its southern side, the two show no disposition to mix; they keep an undisturbed anticyclonic region between

them as a sort of buffer. If the westerly current has an easterly current on its northern side . . . the two currents engage one another forthwith and a circular storm results."

The place of origin of tropical cyclones of the North Atlantic and the "Far East" has been recently discussed briefly by the "Chief of the Weather Bureau" (118) in a reply to an inquiry sent him. The following is quoted:

> It is a definitely known fact that tropical cyclones have their origin within the region of calms of the Tropics, commonly known as the doldrums, and that cyclones form in this belt of calms only when it lies at an appreciable distance from the Equator. Now if nothing more than still, or relatively still, moist, warm air were essential to the formation of a cyclone of the Tropics then one would expect to find several in operation at the same time when this belt of calms lies say ten or more degrees either north or south of the Equator. But this does not follow, for it is our experience that the major part of a cyclone season may pass without the semblance of a hurricane, and rarely, if ever, do we note more than one cyclone at any one time in the West Indies. The foregoing being accepted as true, we must then seek a contributory cause of the formation of a cyclone outside the still, moist, warm air of the doldrums. Now, if we consider the seeming fact that the loci of tropical cyclonic formation on the North Atlantic are two in number, one the western Caribbean Sea and the other the region about the Cape Verde Islands, where the belt of calms is at times flanked by oppositely directed systems of winds, one of which is the northeast trade of our hemisphere and the other the similar trade wind of the Southern Hemisphere, which after having crossed the Equator comes under the right-hand deflective influence of the earth's rotation, and is changed to a southwest wind system, it is reasonable to assume that these passing wind systems have perhaps much to do with the formation of tropical cyclones. Over the North Atlantic, within the Tropics, it is probably true that this contributory cause is rarely in operation, whereas in the East Indies the southwest monsoon blows during much of the cyclone season and on approaching, but passing to the south of the northwest trade wind system of the North Pacific Ocean, there naturally arise many occasions when the conditions are what may be regarded as ideal for the development of cyclones. Hence the greater frequency of the typhoon. Of course the deflective influence of the earth's rotation plays an important part in the changing of the course of these two primary wind systems (each one being turned to the right), and by doing so lowers the barometric pressure over the intervening region and in addition thereto determines the direction of rotation of the winds of the cyclone itself. Now, if these primary wind systems initiate an incipient whirl, then the condensation of water vapor, and the consequent setting free of latent heat, immediately gives the energy that maintains the cyclone during days and at times weeks. Otherwise, it seems likely the life of the cyclone would be very short.

TIME AND MANNER OF ORIGIN

The time of origin of most tropical cyclones is during the late summer and early autumn. For most regions, 80 to 90 per cent develop during the half of the year which includes summer and fall. However, in all of the great regions tropical cyclones occur in every month, although those of winter and spring are not always "typical."

The seasonal variation in the frequency of storms is generally explained as being due to the position of the belt of doldrums, storms being most numerous when this belt of calms is farthest from the Equator.

But this explanation does not account adequately for the storms of the winter and spring when the doldrums are over the Equator or on its farther side. The variation from year to year is also great, but its causes are unknown. Widespread variations in the atmospheric circulation undoubtedly are factors and some of these may be related to variations in solar activity (p. 108).

MECHANICAL HYPOTHESIS

There have been two opposing explanations of the manner of origin of tropical cyclones—the mechanical and the convectional.

The mechanical hypothesis is the older, but both have undergone considerable modification. The first mechanical hypothesis appears to have been suggested by Dove (54) nearly a century ago. It was supported by Meldrum (122) a half century ago, and by Doberck (51) and by Fassig (60) more recently. In its original form, this hypothesis assumed that tropical cyclones are analogous to the whirls frequently set up by friction between opposing currents of water in a stream. The fact that conflicting winds exist on opposite sides of the chief areas where tropical cyclones originate, lends support to this hypothesis. A serious objection to it, however, is the great velocity often attained by the winds in tropical cyclones, commonly several times that prevailing in the general winds believed to have set up the whirls. Jeffries (102) declares that the whirls between opposing currents in a stream never have a velocity greater than the main currents. Later the simple hypothesis of Dove and Meldrum was modified as to the nature of the whirls. Bigelow (13) and more recently Taylor (178) have postulated that cyclones develop just beyond mountain ranges, areas of abnormally high or low pressure, and also on the leeward side of other irregularities in the course of the general winds, in somewhat the way that eddies develop down stream from bowlders or other obstructions in shallow rivers.

This form of the hypothesis might explain the apparent origin of cyclones in the lee of some mountain ranges and just beyond land areas, but it fails to explain the many storms that originate elsewhere. Furthermore, the apparent origin of cyclonic storms to the lee of mountain ranges is deceptive, for it is known that instead of creating storms, mountain ranges commonly merely cut off the lower portions of storms crossing them, with the result that the disturbance is not very apparent at the surface just beyond the range. Soon, however, the persistent differences of pressure cause cyclonic surface winds again to develop.

A more plausible modification of the mechanical hypothesis has been elaborated by Bigelow (14). Bjerknes (17) in another connection dis-

cusses the counter current hypothesis. According to this modification, tropical cyclones are initiated by counter currents of different temperatures. The colder air moves under the warmer, causing it to rise, and commonly induces condensation. The condensation of water vapor supplies the energy necessary to maintain the storms for a considerable time, once they are started.

The most recent form of the mechanical or counter-current hypothesis is that outlined by Bowie (18), who believes that cyclones always originate between opposing winds.

> Counter currents will and must maintain a belt of high or relatively high barometer between them when they pass to the left of each other in the Northern Hemisphere and a belt of low or relatively low barometric pressure between them when they pass to the right of each other. In other words, in the Northern Hemisphere, the pressure is relatively low between east and west currents when the west wind or current is south of the East. Generally these counter currents and the barometric gradients are in what may be considered to be perfect balance, but not always. If the balance is disturbed in the case of counter currents passing to the right, we would expect any currents that are too strong for their gradients to pull apart further, producing a reduction in air pressure in the intervening belt of already low pressure, and a welling up of the stratum near the earth's surface. As the welling up process goes on, the denser air from the contiguous regions flows inward towards the region over which the air has become rarefied, and gyratory motion will necessarily follow from the deflective influence of the earth's rotation. Moreover, the welling up processes will bring about condensation of water vapor and thus an added impetus will be given the incipient cyclonic formation, and as this condensation goes on as fresh vapor laden air is brought into the cyclonic area, energy for the maintenance of the cyclone is at hand.

CONVECTIONAL HYPOTHESIS

The other chief explanation of the formation of tropical cyclones is the convection theory. It appears to have been first proposed by Espy (59), but received much support from Hann (75), Ferrel (62), and Davis (45). The much quoted description by Milham (124) of a tropical cyclone and its origin is an elaboration of Davis's statement, but the uncertainties mentioned by Davis are ignored and the impression is given that there is very little doubt as to the sufficiency of this theory. Recently Shaw (164) has re-stated the convection theory, making use of new data concerning upper air conditions and the circulation of fluids. Although the convectional theory as stated by the older writers was not acceptable to Shaw, he appears to feel that in its most recent form, it is sufficiently adequate and that the mechanical theory need not be called upon to explain the origin of tropical cyclones. In other words, he believes that the recent attempts of Bjerknes (17) to explain the development of the cyclones of middle latitudes as due to opposing winds need not be extended to apply to tropical cyclones.

Humphreys (84) believes that tropical cyclones are due primarily to

convection over a comparatively large area, but admits that opposing winds may be essential in the initiation of the cyclone. He states:

The atmosphere of a doldrum belt becomes very warm and humid, and therefore frequently is in a state of vertical convection. The upward branches of this convection are nearly always limited to very restricted areas, where they break through, as it were, and often give rise to local thundershowers. Occasionally, however, heating and expansion must take place more or less uniformly over a comparatively extended region. So long as the upward current is gentle and restricted to a small area, the compensating inflow from the sides is also gentle, and can produce only a cumulus cloud and perhaps a thunderstorm. In the event that such a storm is formed, the inflowing counter-current to the ascending warm air is replaced by an equivalent column or sheet of descending cold air immediately to the rear. That is, the loss of warm surface air is compensated by a similarly concentrated and vigorous downflow of cold upper air. Hence, rotary circulation, since it depends upon horizontal inflow from all or at least several sides, is not possible in the case of ordinary thunderstorms, whatever their location.

On the other hand, an approximately equal expansion of air over a relatively large area, whether caused by an increase of temperature, or vapor density, or by both, must lead to an overflow above and a corresponding surface inflow around the outer borders.

Obviously the rate of volume overflow at any time is proportional to the area in question, while the corresponding inflow is proportional to the boundary multiplied by the average normal component of the wind. If the area is circular with radius R, it follows that the rate of outflow above is proportional to 3.1416 R, and the rate of inflow below to 2 (3.1416) RVn, in which Vn is the average radially inward component of the wind at the distance R from the center. But as the two currents compensate each other except as modified by precipitation, explained below, it follows that Vn, other things being equal, is proportional to R. Hence, when the area involved is rather large, one hundred miles, say, in diameter, the relatively shallow and spirally moving compensation or return current may become very perceptible. This at once feeds the entire rising column with excessively humid air that renders it an even better absorber than before of both isolation and terrestrial radiation and increases its rate of expansion, thus initiating, perhaps, a widespread condensation. If so, latent heat thus set free, while it does not actually raise the temperature of the air, reduces the rate of adiabatic cooling from approximately 1° C. to about 0.4° per one hundred meters increase of elevation, and thereby establishes within the rising column temperatures distinctly higher than those of the surrounding air at the same level. In this way the circulation is accelerated, and thereby the rate of condensation and freeing of latent heat increased until, through a growth of size, restricted supply of water vapor, and other causes, a limiting, somewhat steady, state is attained.

When the conditions here described occur at some distance from the Equator the rotation of the earth deflects the inflowing air and establishes a rotation around the region of lowest pressure—an effect all the more likely to occur (perhaps rarely else does occur), when the existing convection takes place along the doldrum boundary between the rather oppositely directed (not opposing) trade winds, the one from higher latitudes, the other from across the Equator. But whatever the radius of curvature, the angular momentum remains constant—the law of the conservation of areas obtains—except as modified by friction and viscosity, and therefore, since surface-drag is effective at but small elevations, the atmosphere at one hundred to two hundred meters above the water may, as it moves inward, soon reach that velocity at which its deflective force is equal to the horizontal pressure gradient. When such velocity is reached, as it obviously may be at any appreciable altitude, inflow at that place necessarily ceases. Near the water, however, this limiting velocity is prevented by surface friction. Hence, as soon as the whirl is well established, it must be fed almost exclusively by the lowest and therefore most humid air. In this way a maximum amount of precipitation, and, through it, a maximum

amount of thermal energy is secured—a condition important to the maintenance of the tropical cyclone, as is evident from the fact that it tends to go to pieces over dry land, especially before it has recurved and become essentially extra-tropical.

A consideration of the two chief theories of origin of tropical cyclones reveals the fact that each has been supported by eminent cyclonologists, and that recently four eminent students of the subject, each of whom presumably made use of all available data, arrived at radically different conclusions. Humphreys and Shaw believe that convection is the chief agency, while Bowie believes that the storms are developed by opposing currents. Jeffreys finds objection to the adequacy of either theory, and holds that both convection and counter currents contribute. I, likewise, believe that both agencies contribute. The incipiency of the disturbances is apparently due to a gradual uniform decrease in atmospheric pressure over a relatively large area, one hundred miles or so across. This decrease is due to the accumulation of an excess of warmth and moisture often supplemented by the effects of opposing winds on two sides of the region, as set forth by Bowie. When the difference in pressure between the central area and the surrounding region is sufficient to overcome the inertia, the friction, and the drawing-out effects of the opposing winds (where they are present), the cooler, drier, and heavier air moves inward. The deflective effect of the earth's rotation tends to convert the inward-moving currents into a gyratory whirl; the higher the latitude, the stronger the tendency. Near the Equator it alone is probably not sufficient to start a whirl, but if it is assisted by opposing winds, as by the deflected trades that have crossed the Equator, or by winds induced by disturbances in higher latitudes, a whirl may start almost over the Equator. Once initiated, the whirl is stimulated by the energy released upon the condensation of moisture brought into the area by in-blowing winds. After a strong cyclonic movement is produced, the disturbance becomes independent of the conditions of its origin, and moves off as a whirl in the atmosphere, comparable in many ways to a whirl in a stream of water. Shaw has discussed this stage rather satisfactorily.

FUNDAMENTAL CAUSES

The fundamental causes of tropical cyclones are of two types: A—The physical agents and laws that produce the storms when conditions are favorable; and B—The causes of the favorable conditions.

A. Four physical forces or causes cooperate to produce a cyclone where conditions are favorable:

(1) The force of gravity draws air in toward the center, where a partial vacuum exists. This is the agency which produces the wind.

(2) The deflective effect of the earth's rotation turns the wind from

the path prescribed by the pull of gravity, which is at right angles to the isobars. The result is that the wind spirals in towards the center of the low, entering in a counter-clockwise direction in the Northern Hemisphere and clockwise in the Southern Hemisphere.

(3) The third cause cooperating to produce cyclonic storms is that described as the first law of motion, namely that any body in motion travels in a straight line until deflected. This force therefore supplements the deflective effects of the earth's rotation, wherever that effect is considerable, by retarding the approach of the in-spiraling air to the storm center. In other words, the pull of gravity is unable to bring air into the low and fill it up as promptly as it could if this law did not operate. This force is ineffective only near the Equator where the deflective effect of the earth's rotation is so slight that it does not succeed in deflecting the air from the path prescribed by gravity. Whenever, because of a steep barometric gradient and little friction, the winds in a whirl attain a great velocity, the combined effect of the tendency for moving particles to travel in a straight line (which increases with the velocity), and the deflective effect of the earth's rotation, may counteract the pull of gravity sufficiently to cause a slight drawing-away of the air from the storm center, thus increasing the barometric gradient and the wind velocity. When the whirling winds are swift, the reduction in pressure in the center of the whirl is increased somewhat by the frictional withdrawal of some of the air in the center. The air withdrawn is that swept along with the air whirling around the center, and that carried out with the drops of water which have a strong tendency, because of their superior weight, to fly outward (85).

(4) A fourth agency is the reduction in pressure associated with condensation of water vapor. It intensifies a cyclonic circulation already set up. Condensation reduces pressure by releasing the large amount of energy required to evaporate the water, and also, more directly, by removing a part of the air, namely, the water vapor that condenses and is precipitated as rain. The released energy decreases the vertical temperature gradient, or as it is commonly and incorrectly expressed, "warms the air." As a result, the air expands upward and then outward above, thus reducing the pressure below. The other reduction of pressure due to condensation follows from the fact that water vapor displaces a certain amount of the other constituents of air. Yet, because water vapor is much lighter than nitrogen and oxygen, moist air in the open is relatively light air. Condensation of the vapor and its precipitation removes from the air the three or possibly four per cent of its weight formerly made up by the vapor and temporarily reduces the air pressure to that extent. As condensation and precipitation commonly takes place in tropical cyclones very rapidly and in

large amounts, especially toward the storm's center, the result is a temporary notable reduction in pressure and a steepened barometric gradient in the direction of the center.

B. Favorable conditions for the origin of tropical cyclones include the presence of a considerable area (100 miles or more across), where the pressure is comparatively low, where the humidity is great, where a general expansion of air upward instead of convectional overturning has taken place, and where opposing winds occur just beyond this area of relative calm. This low pressure area must lie in, or move into, latitudes at least three or four degrees from the Equator.

Problems connected with the fundamental causes include the following: (1) Why do conditions conducive to cyclone development occur oftener in one year than another in any region and over the entire earth? (2) Why are the areas of origin of storms so localized? (3) Why are storms not more frequent? (4) Are favorable conditions for cyclone development related to solar or electrical changes, or are they induced by a more or less fortuitous combination of terrestrial conditions?

Not enough is known to permit of a full discussion of these questions. However, if the favorable conditions for cyclonic development are due to a more or less accidentally favorable combination of terrestrial conditions—wind, air, temperature, humidity, ocean surface temperatures, insolation, and other factors—the time and place distribution of storm origin could be largely explained by the fact that several influences must be almost completely favorable in order that cyclones may develop. Such a combination is rare in the greatly disturbed atmospheric world with its many moving cyclonic disturbances in almost all latitudes, its shifting wind belts and ocean currents, its marked seasonal changes, its irregular distribution of land and water and its variable sun (36, 90).

ENERGY OF TROPICAL CYCLONES

The amount of energy required to produce gales over an area hundreds of miles across is enormous. The air in a cyclone three hundred miles across and a mile high weighs at least three hundred billion tons, or more than three thousand times as much as all of the ships afloat. Yet this much air, or more in large storms, is set in rapid motion in the few days required for the storm to develop. During the period of the greatest intensity, the air involved has an average velocity of at least forty miles an hour or twice the speed of a fast steamer. To set in rapid motion this enormous weight of air, in say ten days, requires more energy than an engine delivering seven and a half trillion horsepower could deliver in that

time. In other words, the initiation of a single normal tropical cyclone requires during those few days, more than one hundred and fifty thousand times as much power as is developed in the same time by all the steam engines, motors, and hydro-electric plants in the United States.[2]

Calculations indicate that the condensation required to form an inch of rain a day liberates as much latent energy per square meter as is generated by a one horsepower engine in a day. Since in a tropical cyclone, rain commonly falls over an area of two hundred billion square meters, and cloud formation is even more extensive, it follows, according to the calculations of the preceding paragraph, that the condensation of enough moisture to form 35 inches of rain a day would be required to yield the energy necessary to set the whirl in motion.

Although there are a few records of the condensation of such vast totals of daily precipitation, they are far too rare to support the hypothesis that condensation affords an adequate source of the energy of tropical cyclones. Lodge (112), Dines (50), and Davis (45, p. 200) who have advocated the sufficiency of condensation as the source of energy of tropical cyclones apparently considered the maintenance of the storm after the whirl is established, rather than the energy involved in setting the vast mass of air into rapid motion. When once the whirl is well established, the energy requirements are far less.

Since condensation is not sufficient to yield enough energy to start a tropical cyclone, other sources of energy must contribute. The absorption of radiant energy by the moist air is doubtless important early in the formation of the disturbance, for this absorption helps create the central area of lower pressure with the surrounding zone of higher pressure that leads to the inblowing winds. After convection has created cloudiness, a larger amount of radiation is absorbed by the atmosphere and convection is augmented, with consequent increase in wind velocity. The condensation associated with cloudiness adds further energy. The precipitation of five inches of rain a day is common in tropical cyclones, which means the release of as much energy as a one trillion horsepower engine could deliver in a day. This is sufficient to overcome friction and to keep the air moving at hurricane velocity. After the storm has reached middle latitudes, it may remain a powerful disturbance in spite of a lack of condensation. Some cyclones, indeed, cross a continent without yielding much rain. The inertia helps them do this, but as friction is constantly operating, storms that do not weaken must be maintained by the absorption of enough solar energy by the clouds to overcome the friction, or by the

[2] For assistance in these calculations, credit is due to Dr. R. R. Ramsey, Professor of Physics, Indiana University.

effects of the contrasted temperature of winds from higher and lower latitudes. Temperature contrasts among the in-blowing winds are characteristic of cyclones except near the Equator. Such contrasts, according to Margules (117), Gold (69), Jeffries (101), Bjerknes (16), and Shaw (163), help maintain the whirl. The colder winds from higher latitudes under-run the warmer winds from lower latitudes, causing them to rise and condense part of their moisture, thus maintaining cloudiness. The cloudiness results in a local increased absorption of solar energy. This helps maintain the comparatively low pressures, which otherwise would soon disappear. Another influence helping to maintain the lower pressure is the tendency of the air to circle round the low instead of flowing directly into it.

Shaw (164) states that the chief cause of the death of cyclones is their failure to secure a sufficient supply of warm moist air. This condition is brought about when the cyclone moves too far from the ocean or other source of moisture, or when it comes into too cold a region, where all the winds are cold.

The energy of tropical cyclones is procured from the sun, just as is the energy of coal, oil, and water power. It enters the storm by the absorption of the sun's radiant energy in three ways: (1) by the water vapor, (2) by the clouds, and (3) by the release of the latent energy when condensation occurs. The solar energy is effective in making winds, by its production of higher temperatures and lower pressures near the storm's center, this condition giving a barometric gradient in that direction. The deflective effect of the earth's rotation interferes with the prompt filling up of the partial vacuum thus created, and hence prolongs the blowing of the wind, but neither the earth's rotation nor the equally important pull of gravity can be considered as a positive source of the energy of tropical cyclones.

CAUSES OF STORM MOVEMENTS

The movement of tropical cyclones along their courses is commonly attributed to the general movement of the air of the region in which they occur. Their movement westward in low latitudes, for example, is attributed to the easterly winds—the trades; and their movement eastward, after recurving, is attributed to the westerlies. Their movement away from the Equator is due to the combined influence of three or four agencies: (1) the deflective force described in Ferrel's law; (2) the trades; (3) the counter trades, and (4) the winds characteristic of the western sides of anticyclonic areas. The deflective action of the earth's rotation, formulated in Ferrel's law, increases with the latitude. Hence, winds

approaching the center of the whirl from the direction of the Equator move more directly toward it than do those approaching it from the poleward side, the latter having a stronger tendency to spiral around it as they approach. The winds from the Equator tend, therefore, to push the storm center into higher latitudes. If the storm is thus pushed from the belt of the trades into the westerlies, it follows a roughly parabolic course, moving (in the Northern Hemisphere) northwestward in the Trade Wind belt, northward in the belt between the trades and westerlies, and northeasterly in the belt of the westerlies. The counter-trades assist the movement of the storm into higher latitudes whenever the storm extends high enough to reach them, for the counter-trades blow poleward and somewhat eastward. They are made up of air which has risen in the doldrums and is moving into higher latitudes above the trades. A third influence often assisting the movement of tropical cyclones into higher latitudes is the winds which are characteristic of the western sides of the anticyclones. Such winds blow away from the Equator. (See page 99.)

The trades themselves, because they blow somewhat towards the Equator (from the northeast or east-northeast in the Northern Hemisphere) might be thought capable of pushing the storm into somewhat lower latitudes. But the fact that the storm-whirl is always counter clockwise in the Northern Hemisphere, means that the trades accelerate the winds on the poleward or northwestern side of the storm in the Northern Hemisphere, and retard the cyclonic winds on the equatorward or opposite side. Winds that are accelerated, tend to follow the isobars rather than to spiral in towards the center, and those that are retarded tend to blow more directly towards the storm center, thus pushing it into higher latitudes. This influence, therefore, supplements the influence of the deflection due to the earth's rotation, and the influence of counter-trades and anticyclonic winds in pushing the storm into higher latitudes.

The irregular movements of tropical cyclones are due largely to the presence of areas of high pressure moving poleward. Maxwell Hall (74), writing of the tropical cyclones of the West Indies, states that no hurricane is an isolated phenomenon; that it is always related to and controlled by some adjacent area of high pressure. Bowie (18) states that in the Northern Hemisphere a cyclone moves so as to keep the area of high pressure to the right of its course.

If the adjacent area of high pressure is essentially stationary during the life of the storm, the cyclone follows a regular course after approaching it, first westward along its equatorward border and then poleward, recurving around its westward side. The so-called permanent areas of high pressure over the oceans between the trades and the westerlies

often are sufficiently powerful to cause the tropical cyclones to move thus along their margins, and to pass poleward near the western sides of the oceans or over the adjacent coasts, provided low pressures prevail over the coasts, as they often do in Summer and Fall. The average path of the hurricanes of the West Indies bears this relation to the Bermuda high. However, the so-called permanent highs are by no means constant or even persistent. They change their shape and intensity frequently, and may disappear altogether in certain longitudes. Hence, many tropical cyclones are able to move northward on a path farther east than that followed by others. Indeed, not a few cross the area ordinarily dominated by high pressure.

The irregularities in cyclone paths, due to fluctuations in the semi-permanent highs are not so erratic, however, as those associated with rapidly moving anti-cyclones. Many anti-cyclones or highs extend from mid-latitudes into the margin of the tropics. Some of them expand and contract quickly or move rapidly eastward. The courses of tropical cyclones which are controlled by such rapidly changing high pressure conditions may be very aberrant. Some storms are driven temporarily into lower latitudes, or even forced to make loops. Other storms recurve very sharply, moving eastward in very low latitudes. Still others follow sinuous courses.

The winds blowing out from moving anti-cyclones are believed by Bowie (18) to play an active part in causing the cyclones to move westward along the southern margin of the high and northward along its western margin. This is because easterly winds prevail on the equatorside of any high in the Northern Hemisphere, and because winds blowing away from the Equator prevail on the western side. The easterly winds are very similar to the trades.

Many winter storms, approaching the coasts of Asia from the east, are diverted by the high pressures that normally prevail over at least the central part of that continent. The tendency, mentioned by Bowie, for cyclones in the Northern Hemisphere to keep the barometric high on the right of their course, causes some storms to travel southwesterly along the coast, instead of northwesterly or northerly. In general, the high pressures over Asia in winter protect that continent from damage from winter tropical cyclones, which either recurve some distance off shore, or weaken so decidedly before going far into the high that they are no longer storms. Some, however, become violent again after having recurved and reached the ocean (p. 85).

In order to forecast successfully the course that a given storm will

follow, we must, as Bowie has well said, look beyond the immediate environs of the cyclone. Synoptic charts of pressure, temperature, surface winds, free air winds, and clouds over a wide area are essential to an understanding of a particular storm. Such charts for several recent West Indian hurricanes have been published (18).

PREDICTING STORMS

ANALYSIS OF AUSTRALIAN RECORDS

The advantage which would result from successful prediction of hurricanes is so great that many attempts have been made to find some method of forecasting them. So far these efforts have met with failure. It probably always will be impossible to do more than state the probabilities of a hurricane occurring somewhere in a rather large region, because many factors influence atmospheric circulation, and also because the hurricane usually damages only a narrow zone. For example, Queensland might experience an unusually large number of hurricanes in one year, and yet these storms might recurve off the coast, passing off without doing much damage, or they might enter the state in sparsely settled regions without causing much destruction. On the other hand, in a year during which only one hurricane occurred, if the center passed over some town, even a storm of average severity might do a great deal of damage.

But in spite of the present impossibility of making satisfactory predictions, the great interest in forecasting may warrant some statements as to apparent probabilities. With this in mind, the distribution of hurricanes in Australia, as shown in Table 17, has been studied. The following generalizations are offered since they may have some slight forecasting value.

Taking Australia as a whole, there seems to be a strong tendency for a year of many hurricanes to be followed by a year of few. Each of the five years of few storms since 1890 followed a year of many storms. In the years before 1890 the same relation is indicated, although the relative incompleteness of the data makes the earlier records less valuable for study. However, the records show that several years in succession have had about the normal number of blows.

There are some indications of a four-year cycle between maxima. A ten to twelve-year cycle is also faintly suggested by the data at hand, the minima occurring in 1873, 1885, 1905, 1917, and the maxima in 1872, 1884, 1894, 1909, and 1916. The records are not long enough, however, to prove the existence of either of these cycles. It was thought possible that the storminess of December might give some indication of the probability of storms in the following months. However, there seems to be no definite relationship. Of the Decembers with a hurricane somewhere in Australia or Fiji, about one-third were followed by months with fewer than the normal number of storms and about one-third by months with more than the normal number.

In Queensland, whenever there have been hurricanes in December or January, the prospects of having no storm during the rest of the season are very poor, about 1:12. Instead there are nearly equal chances that the rest of the season will have more than the normal number of storms. On the other hand, in those seasons during which no blow occurred in December or January, the likelihood that there will be no storm during the rest of the year is about equal to the chance of there being an abnormally large number. In about one-fifth of the years the first storm of the season occurred in February, and in about another one-fifth the first occurred in March or later.

In Western Australia, a December or January hurricane is followed by a blow later in the season nearly four times as often as it is followed by none. If there is no storm anywhere in Western Australia in December or January, the prospect of there being no storm during the rest of the season is about as 11:17, and the prospects of there being two storms is about as 3:11.

In about one year in five, on the average, a hurricane occurs somewhere in Queensland during April to July, inclusive, and in about one year in six in Western Australia.

ANALYSIS OF TYPHOON RECORDS

It has interested me to make an analysis of the storminess of the "Far East," with a view to finding a possible basis for prediction of typhoons. The material used are the records listed in Table 10.

The first month of the main typhoon season is July. Does excessive or slight storm frequency in July throw any light upon the storminess of the year as a whole? Apparently it affords the basis for a good guess. Of 41 years, the seven years that had five or more typhoons in July, instead of the normal 3.4 storms, were all years of more than the average number of storms (22.3 a year). These seven years had an average of 27 storms each. Thus the occurrence of five or more storms in July strongly indicates that the year will be abnormally stormy. Correspondingly, the occurrence of fewer than three storms in July suggests that the year as a whole will have comparatively few storms. The evidence for this conclusion is that of the nine years in 1880-1920, during which fewer than three typhoons occurred in the "Far East" in July, none had over 24 typhoons, the highest five being 21, 22, 23, 23, and 24. The average number was 16.3 instead of the "normal" 22.3.

Wide departures from the mean in the storminess of August are also usually related to corresponding departures for the year as a whole. For

example, during the 10 years of the period studied in which five or more typhoons occurred instead of the "normal" 3.6, there was an average of 26.3 storms in the year as a whole instead of 22.3. Only three of the years had fewer than 25 storms, but one had only 16, the other two of the three having 20 and 21. The margin is still narrower in respect to the years with few August storms. The nine Augusts with fewer than three storms are followed by an average of 9.4 storms in the rest of the year instead of by the "normal" 10.4, the average for the entire 41 years. However, five of the nine years had more than the average number, making a forecast on this basis quite unsatisfactory.

The relationship of September storminess to the storminess of the following months of the year appears closer, according to the data of Table 10, than that of August. On the average, September has 4.1 storms and the remainder of the year 6.3. In the eleven years during which September had five or more storms, the following months had an average of seven storms. Only one year had less than five storms and that year had four. On the other hand, the seven years of only one or two September storms, each had an average of only 4.4 storms, instead of the "normal" 6.3 storms, during the following months.

The storm frequency of October appears to be no clear indicator of the storm frequency of November and December, as half of the six Octobers, with five or more storms each, are followed by less than the normal number of storms, and the average is only slightly over the normal (3.51: 3.1). The 13 Octobers with fewer than three storms are likewise followed by months having more than the average number of typhoons in more than half of the years. Indeed, the average storminess of November and December was slightly above the normal during the 13 years when the October storminess was distinctly below the average (fewer than three storms in contrast with an average of 3.2).

June is another month that affords only a very slight basis for the prediction of typhoon frequency in following months. The eleven years of the period 1880-1920, in which no typhoon was recorded in June, had an average of 15.8 storms for the following months in contrast to 17.7, the mean for the 41 years. However, four of the eleven years had more than the average number of storms. The six years in which three or more storms occurred in June had an average of 19 storms, instead of 17.7, in the remaining months. However, one-third of the six had less than the average number.

The storm frequency of the first half of the year appears from Table 11 to afford a slight basis for predicting the storminess of the rest of the year. The ten years in 1880-1920, during which there were

fewer than three typhoons instead of the "normal" 4.6, were followed by an average of 15 storms during the following six months instead of by the "normal" 17.7. Only three of the ten years had over 15 storms, but those had 21, 22, 21 each. Nine of the 41 years had eight or more storms in the first six months instead of 4.6. These nine years had an average of 20.6 storms in the last six months instead of 17.7. Only two years had less than 20 storms, but they had only 13 and 15 each.

The two months, June and July, had a total of 4.8 typhoons, on the average, during the years 1880-1920. However, 14 of the 41 years had fewer than four typhoons in these months, while 13 years had six or more. The 14 years of comparatively few storms in June and July had an average of 6.8 storms in August and September instead of the "normal" 7.7. Only four of these 14 years had fewer than six storms in the following two months, but those had five, five, four, and two each. The 13 years during which June and July were exceptionally stormy, having six storms or more, were followed, with one exception, by two months of more than the average storminess (an average of 8.3 storms instead of the "normal" 7.7). One years of the 13, however, had only three storms in August and September.

It therefore appears that the storm frequency of any month or group of months usually bears some slight relationship to the storminess of following months. A month or period having notably more than the average for that period is rather likely to be followed by other months of exceptional storminess. Likewise, a month or period having distinctly fewer storms than the average will probably be followed by other months with fewer than the normal number of storms. However, exceptions to these general rules are numerous, and it must be understood that any forecast of this sort based on the foregoing paragraphs applies to the "Far East" as a whole and not to any particular locality.

In the western North Pacific, as in Australia and elsewhere, there is now no known method for accurately predicting the exact path that a future tropical cyclone will follow. Although the probabilities may indicate more than the normal storminess in the following month or period, it by no means follows that more than the average damage will be done in any particular locality.

STORM FREQUENCY AND SPOTTEDNESS OF THE SUN

A number of investigators have reported a correspondence between the eleven year cycle in the spottedness of the sun and the frequency of tropical cyclones. The evidence presented fifty years ago by Meldrum (122) in respect to the tropical cyclones of the Mauritius region of the South Indian

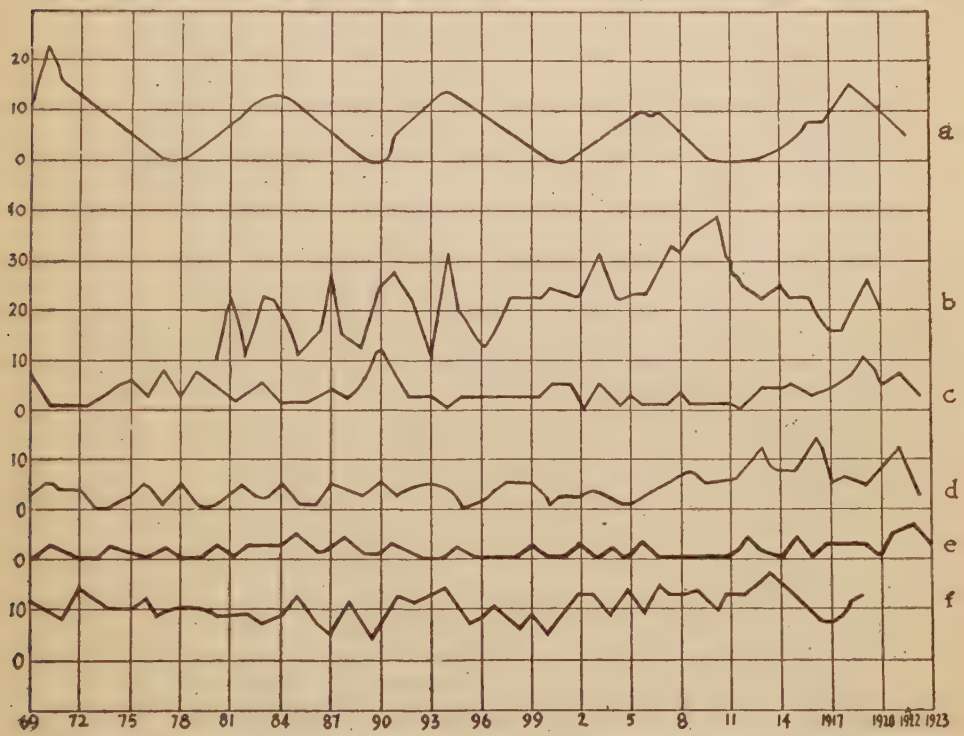


FIGURE 17.—Curves showing annual frequency of tropical cyclones in comparison with annual variations in the spottedness of the sun for the years 1869-1923: a, the annual number of sun spots—data for the years 1869-1889 from Wolfer (205); for the years 1890-1922 from Lockyer (111); b, the annual number of typhoons in the Western North Pacific (the "Far East") based on table 20; c, annual number of hurricanes in the South Pacific based on table 7; d, annual number of hurricanes in Australia; e, annual number of hurricanes in the eastern North Pacific; f, annual number of hurricanes near Mauritius in the South Indian Ocean, latitude 50°-70° E., based on data compiled by the Royal Alfred Observatory (197).

Ocean was especially emphatic. Later studies (135) for that region have weakened the evidence but there seems to be some relationship.

Any satisfactory study of annual cycles requires homogeneous data extending over a period long enough to include a number of cycles. The

lists of tropical cyclones now available are not complete enough for a period long enough to satisfactorily test the hypothesis that the storms vary with the sunspot cycle of approximately eleven years. However, the lists compiled for this Bulletin afford a more satisfactory basis for testing this hypothesis than any previous lists dealing with Pacific hurricanes.

The data analyzed in figure 17 fail to disclose any striking correspondence between the annual frequency of tropical cyclones and the spottedness of the sun. The storm frequencies shown by the curves of figure 17 have been further analyzed in Table 26. For the "Far East" the data are from Table 11 and involves four cycles; the Eastern North Pacific data are from Table 15 and extend over seven cycles, although the record is by no means reasonably complete for that many cycles; South Pacific data are from Table 8 and extend over eight cycles; data for the western South Indian Ocean involve seven cycles, and are probably fairly complete.

TABLE 26. AVERAGE ANNUAL NUMBER OF TROPICAL CYCLONES COMPARED WITH THE SUN SPOT CYCLE

	Western N. Pacific	Eastern N. Pacific	Australia	Western S. Pacific	W. South Indian Ocean
Year of sunspot maximum	23	1.4	4.2	2.75	5.3
Year of sunspot minimum	19.3	0.4	4.5	2.87	5.0
Three years: Maximum and the year before and after	20.8	1.0	4.3	2.3	5.3
Three years: Minimum and the year before and after	22.8	1.0	4.9	3.8	5.1
Years of increasing storminess (year after minimum to year before maximum)	22.2	0.9	4.3	3.2	5.55
Years of decreasing storminess	22.4	1.4	5.2	2.4	4.4

Although there are several suggestions of a relationship between storm frequency and the so-called eleven year sunspot cycle, it is clearly evident that this analysis of the storms of the Pacific fails to give much support to that hypothesis. In order to make a more conclusive test of the hypothesis that some relationship exists between the spottedness of the sun and the frequency of tropical cyclones, a month by month comparison between these phenomena has been made. A monthly comparison is a far more satisfactory test of this hypothesis than is the annual, for two chief reasons: (1) it greatly reduces the significance of the briefness and the incompleteness of the storm records, the longest of which covers only a very few of the eleven year cycles; (2) it compares two phenomena of more nearly comparable duration. Tropical cyclones require only a week or two of favorable conditions in order to originate. Likewise, the spottedness of the sun varies from day to day and from week to week. The mean annual spotted-

ness is made up of the average of the monthly means, and therefore two years having the same annual mean may differ radically so far as the spottedness during the cyclone season is concerned, provided an excess or deficiency in that period is offset by a deficiency or excess in the rest of the year. Table 28 is based on a comparison between the monthly spottedness as reported by Wolfer (205) and the storminess as given in the tables.

In Table 27 the comparisons are made between the six months in which most cyclones occur, because the storminess of the other six months is too slight to have much influence upon the total.

TABLE 27. NUMBER OF TROPICAL CYCLONES IN STORMIER HALF YEAR, COMPARED WITH SPOTTEDNESS OF THE SUN, BY MONTHS

A. Typhoons: June-November, 1880-1920, inclusive.

Spottedness of the sun	Typhoons		Total Months		Average Number of Storms Per Month
	Number	Per Cent	Number	Per Cent	
0-40	384	52.6	126	51	3.04
41-80	275	37.6	91	37	3.02
81+	71	9.7	29	12.6	2.4

B. Hurricanes between Hawaii and Mexico—Central America: June-November, 1850-1922, inclusive.

Spottedness of the sun	Hurricanes		Total Months		Average Number of Storms Per Month
	Number	Per Cent	Number	Per Cent	
0-40	46	55.4	224	52	.20
41-80	26	31.3	146	33.3	.18
81+	11	13.2	68	14.8	.16

C. Hurricanes in western South Pacific: December-May, 1850-1922, inclusive.

Spottedness of the sun	Hurricanes		Total Months		Average Number of Storms Per Month
	Number	Per Cent	Number	Per Cent	
0-40	121	61	224	50.2	.54
41-80	64	32	147	34	.44
81+	14	7	61	16	.23

D. Hurricanes in Australia: December-May, 1850-1922, inclusive.

Spottedness of the sun	Hurricanes		Total Months		Average Number of Storms Per Month
	Number	Per Cent	Number	Per Cent	
0-40	115	53.2	224	50.2	.51
41-80	67	31.0	147	34.0	.46
81+	34	15.8	61	16	.56

E. Hurricanes near Mauritius (50-70 E.), South Indian Ocean: December-May, 1850-1919, inclusive.

Spottedness of the sun	Hurricanes		Total Months		Average Number of Storms Per Month
	Number	Per Cent	Number	Per Cent	
0-40	164	50	210	50	.78
41-80	119	36	143	35	.83
81+	47	14	61	15	.77

Examination of sections A, B, C, D, E of Table 27 reveals the fact that in the Pacific storminess on the average varies inversely with spottedness;

that in and near Australia the 16 per cent of the months having a spottedness of over 81 had most storms and still further west, in the region near Mauritius, in the South Indian Ocean, storminess varies in still another way, opposite to the variation in Australia.

Table 27, like Table 26, appears to suggest some relationship between spottedness and tropical cyclones, which relationship differs in different regions, and is weak in all of these regions. Furthermore, a more detailed study (Table 28) of the storminess of the Western North Pacific, the region where storms are most fully recorded, and most numerous, suggests that a very complex relationship occurs, if any, for storminess increases with spottedness when spots are few, then diminishes, but later increases when spots are many. In all of the four Pacific areas the few months having a spottedness of more than 120 had most storms but the figures are too small to prove anything.

TABLE 28. NUMBER OF TYPHOONS IN STORMIER HALF YEARS, 1880-1920, COMPARED WITH THE SPOTTEDNESS OF THE SUN, BY MONTHS

Spottedness of the Sun	Typhoons		Months		Average Number Storms Per Month
	Number	Per Cent	Number	Per Cent	
0-20	231	33	81	33	2.8
21-40	153	19.6	45	28	3.4
41-80	275	37.6	91	37	3.02
81-120	57	7.8	25	11	2.3
120+	14	1.2	4	1.6	3.5

TROPICAL CYCLONES OF THE ATLANTIC AND INDIAN OCEANS

WEST INDIES

The tropical cyclones (commonly called hurricanes) of the West Indian Region, have received much study. The contribution by Vines (190) was extended by Garriott (68), and a fuller discussion was published by Fassig (60). Newnham (135) summarizes the work of Fassig and adds data concerning the storms of 1912 to 1919. An important paper has been contributed by Bowie (8) on the movements and origin of the West Indies hurricanes, and a special study of the storms has been made by Mitchell.

Mitchell reports 234 tropical cyclones in this region in the 36 year period, 1881-1922. Of these 118 were true hurricanes, 58 were cyclones of uncertain status because based on insufficient data, and 59 were of minor intensity. None of these 234 storms occurred during the months January to April inclusive, only one in May and two in December. Day (46, 47) reports 7 in 1922, and 6 in 1923.

The data given by Newnham (135) shows that on the average, 4 hurricanes occur a year, but in four of the years 1876-1919, none occurred, and in five of the years 8 or more occurred. September, with 34 per cent of the storms is the stormiest month, followed by October with 28 per cent; August has had 24 per cent; June and July each 5 per cent, and November 3 per cent. That some hurricanes occur during the months January to April is suggested by the fact that Poey (145) records 5 in January, 2 in February, 6 in March, and 1 in April, during the 350 year period, 1493-1855.

The most important results of Mitchell's study are: (1) The great majority of tropical cyclones during the period, 1887-1923, inclusive, developed either over the western third of the Caribbean Sea or far to the eastward of the Lesser Antilles, especially in the vicinity of the Cape Verde Islands, and none developed over the eastern two-thirds of the Caribbean Sea; (2) The influence of anticyclones over the direction of progress of tropical cyclones is very marked; (3) Tropical cyclones recurve to the northward and northeastward at the first favorable opportunity, irrespective of longitude or time of year; (4) When the paths of tropical cyclones describe a loop, it is always to the left.

Newnham (135) plots the average point of recurve as follows:

	LONGITUDE	LATITUDE
June and July	28 N	87 W
August	30 N	83 W
September	28 N	81 W
October	25 N	80 W

The velocity in miles per day is given as follows:

FIRST BRANCH, BEFORE AND DURING THE RECURVE

NUMBER OF DAY FROM ORIGIN	MAY TO JULY	AUG.	SEPT.	OCT.	YEAR
1	273	357	292	224	297
2	248	325	252	223	272
3	210	285	247	201	250
4	273b	285	261	260	270
5	400a	279	210	251b	254

SECOND BRANCH, STORMS TRAVELING EASTERLY

DAY OF EASTERLY TRAVEL	AUG.	SEPT.	OCT.	YEAR	MAY TO JULY
1	279	257	260	249	258
2	340	383	408	401	391
3	.....	356	495	428	457
4	.....	200	404b	497	401

a For 3 examples only; *b* 4 or 5 examples; all others, with one exception, are the average of at least 9 storms.

EASTERN NORTH ATLANTIC

Cyclonic storms of two sorts occur off the west coast of North Africa, and many storms that afterwards affect the West Indian region originate near the Cape Verde Islands (126). Furthermore, numerous small storms, comparable perhaps with weak tornadoes, originate in the Sahara and move westward, many of them reaching the coast. These are discussed by Newnham (135).

THE BAY OF BENGAL

The storms of the Bay of Bengal have been studied by Elliott (58). The more recent storms are discussed soon after their occurrence, in the Indian Monthly Weather Review. Newman (135) gives a summary of the occurrence, and courses of the storms occurring up to 1912, and Schück (159) tabulates the origin and the frequency for each five-degree square in this region.

On the average, ten cyclones occurr annually in the Bay of Bengal. About two of them are severe hurricanes, four are moderately severe, and four are feeble. July, August and September each have from 15 to 19

per cent of the storms; June has 12 per cent; October, 14 per cent, and November, 10 per cent.

The general direction of the storms is northerly upon the sea. Those that travel far upon the land generally move northwesterly. A few recurve and travel easterly. Newnham states:

> In the early stages of formation, the rate of advance is very slow, usually increasing progressively until the storm is fully formed. When fully formed, the usual velocity is from 10 to 14 miles per hour, or roughly, 240 to 280 miles per day. In general, the rate of motion of a fully developed storm continues uniform while at sea, but immediately on making land there is usually a considerable increase both in velocity and intensity, after which the storm usually dies away.

THE ARABIAN SEA

A memoir by Dallas (43) deals with the storms in the Arabian Sea recorded before 1889. Newnham (135) discusses the storms of 1890-1912 from information given in the Indian Monthly Weather Review and in the Pilot charts of the Indian Ocean and Arabian Sea. Schück (159) tabulates by five degree squares the origin and frequency of storms for this region.

On the average, about two cyclones occur a year in the Arabian Sea. In monthly occurrence they are notable in showing two well marked maxima, in May-June (11 and 23 per cent, respectively), and in October-November (21 and 17 per cent, respectively). Cyclones are very rare or lacking during February and March, when the winter monsoon is blowing steadily, and in August, when the Summer monsoon is at its height.

THE SOUTH INDIAN OCEAN

The storms near Mauritius have been studied by Meldrum (122), Köppen (109) and Claxton (33). Their conclusions are summarized by Newnham (135). The studies of Schück and others have been summarized by me (197).

From the evidence at hand it appears that rather more than a dozen tropical cyclones occur annually, on the average, in the South Indian Ocean. They are most frequent in the general vicinity of Mauritius (from Madagascar to longitude 70° E.) but a storm occurs every year or two between Madagascar and Africa, and one to six generally occur east of longitude 70° E. Of 488 storms studied by me (197), January and February each had approximately 25 per cent, March had 25 per cent, April and December each 10 per cent, November 5 per cent, and May 4 per cent. Storms are lacking or extremely rare in the four months June to September.

Most of the published tracks of storms in South Indian Ocean are fairly straight or semi-circular, parabolic curves with the apex of the recurve not far from latitude 20° S. (latitude 17° S. in November and December; 22° S. in January, and February; 21° S. in March; and 15° S. in April and May). Most of the storms travel southwesterly or southerly until reaching about latitude 20° S., south of which the prevailing direction is south-southeast to about latitude 30° S. However, a few storms travel nearly due west north of Mauritius (latitude 20° S.), and a very few recurve sharply well north of latitude 20° S. and move eastward in latitudes where the normal storm is traveling southwestward.

Meldrum (122) classified more than one-fourth of the storms studied by him as "stationary." However, the fuller records of recent years have revealed no storm that was actually stationary, although some advanced slowly and did not travel far. The following table, adapted from Newnham (135), shows the velocity in miles a day of all the charted storms for the six years 1903-1908:

	MEAN	HIGHEST	LOWEST
First Branch	191	401	82
During Recurve	164	332	67
Second Branch	181	400	54

SOME EFFECTS OF TROPICAL CYCLONES ON PACIFIC ISLANDS

DIRECT EFFECTS

THE WINDS

As the descriptions (pp. 147-156) reveal, tropical cyclones cause damage in several ways. The violent winds break off branches of trees, tear off the roofs of buildings and may demolish the entire house. Flying branches, timbers and pieces of sheet-iron roofing in towns add to the damage done. Upon the sea, the hurricane may disable ships, sometimes causing them to flounder, or to be blown upon the shore. Two characteristics of the cyclonic wind increase its destructiveness. The first is its notable gustiness. Instead of blowing steadily at a given velocity, the wind varies in strength suddenly, taking by surprise, as it were, objects endeavoring to withstand it. The calm at the storm's center is the extreme illustration. Often in the "eye of the storm" the calm is so complete that a match may be kept lighted in the open, where a few minutes before a hurricane of eighty or a hundred miles an hour raged. But the calm is usually of short duration; the wind returns with its previous violence.

The second characteristic is the change in direction. Near the storm's center the wind changes direction completely, shifting by jerks throughout half the points of the compass. Indeed, where secondary centers occur, the winds may "box the compass" more than once. Algué (4) and Okada (137) report that such secondary centers are rather frequent in the "Far East." The most sudden, complete change of direction occurs where the central calm or "eye" of the storm passes, because the wind blows in opposite directions on opposite sides of the center. In addition to the systematic changes in wind direction related to the cyclonic circulation about the center, there are innumerable irregular changes of direction related to temporary eddies such as those caused by obstructions. Successive gusts nearly always come from slightly different directions and conspicuous irregular changes of direction are frequent.

The strong winds not only damage structures, but they seriously injure vegetation. Most of the leaves and fruit are stripped from trees, many branches are broken, and some trees are broken off or uprooted. Sugar cane is badly injured by being bruised, knocked down and more or less covered with mud from the fertile river plains flooded by torrential rains. Even the important yam crop, which is beneath the ground, is injured by hurricane winds, for the rather rank stems are broken, and the large leaves torn or bruised.

THE WAVES

The waves, caused by cyclonic storms, break with great fury upon the shore, and may demolish seaside buildings and trees. Wharfs and docks are injured and harbors may be partially blocked by wrecked ships, by drifted sand, or by great masses of coral broken from the reef and transported by the waves. Masses of coral rock "as large as a house" have been tossed about by hurricane waves. The elevated sea level produced near the storm's center by the in-rolling waves and by the partial vacuum greatly increases the destruction along coasts. A barometric minimum of 28 inches causes a local rise of about two feet in the sea level, increasing the height of the waves, and permitting them to advance much farther upon a shelving shore.

When the wind blows violently for several hours upon a low, shelving coast, the sea may advance notably upon the land. If a large flooded river flows into the sea on such a coast, the combined flood, due to the waves, the partial vacuum, and the river's flood, may submerge areas that are normally many feet above sea level. For example, at Nasouri, Fiji, on March 24, 1910, the water in the Reva River rose 35 feet above the normal level, which is here practically sea level (85). (See also page 64.)

The sudden coming of great waves may drown many people upon low coasts, and along the lower stretches of river valleys. During some storms indeed, the water advances as a wall-like wave several feet in height, from which people in its path find escape very difficult. Most of the more than 50,000 persons destroyed in and near Swatow, China, on August 3-4, 1922, probably lost their lives by drowning, as the general sea level rose eight feet, and great waves rolled over the lowland (169). The Associated Press reports that two of these waves reached twenty-five feet above normal sea level. Drowning probably also caused the death of many of the 300,000 persons said to have been killed by the Haifong, China, typhoon of October 8, 1881.

A tidal wave, caused by a tropical cyclone, is said to have drowned 100,000 people of the Ganges Delta on October 31, 1876. A like number died soon after from famine and disease (56).

EXCESSIVE RAINFALL

Rain normally falls in torrents during the passage of a tropical cyclone several inches in an hour or two, and as much as 20 inches in a day. Indeed, records of a fall of more than 30 inches within 24 hours are not lacking. The extreme record so far noted is 46 inches (1,168 mm.) in 24 hours at Baguio, a mountain station near Manila, during the passage of a typhoon, July 14-15, 1911. Coronas (38) reports that during the

four days required for this typhoon to pass, 88 inches of rain (2,238.7 mm.) fell. At Silver Hill, Jamaica, 96.5 inches fell in four days during the passage of a hurricane. In tropical Australia more than 10 inches fell on more than 400 different days in a 25-year period, and a maximum of 35.71 inches fell in 24 hours at Crohamhurst, Queensland, February 2, 1893. At Mt. Molloy, Queensland, 60 inches fell in a three-day period, and there have been many 48-hour periods during the passage of a tropical cyclone, when more than 25 inches fell in tropical Australia (86).

Excessively heavy rainfalls have occurred in other parts of the world during the passage of a tropical cyclone. For example, at Funkiko, Formosa, in three days, July 18-20, 1913, 81.5 inches (2,071 mm.) fell, and 40 inches (1,033 mm.) on August 31, 1911 (38).

In the eastern United States most of the excessive rainfalls have been caused by West Indian hurricanes that have moved northward (23).

Many of the downpours which occur during tropical cyclones besides causing serious floods, erode the soil very badly and influence the amount of uprooting of trees. Certain tropical trees, such as the coconut, usually can be bent until the top touches the ground, without breaking or uprooting. However, if the soil has been thoroughly soaked by excessive rains, uprooting is much more easily accomplished. The damage caused by the run-off of the torrential rainfall causes the damage ordinarily due to flood, including the filling of shallow valleys, which during ordinary rains carry no run-off.

INDIRECT EFFECTS

In addition to their obvious direct effects, tropical cyclones apparently tend to increase the inertia of tropical peoples, strengthen their faith in fatalism and communism and to favor the spread of disease. They also tend to diversify plant and animal life. Disastrous hurricanes probably tend to increase the inertia of the natives. The tendency to "let well enough alone," to abstain from any more exertion than is required is characteristic of the human race, but in some climates is more easily counteracted than in others. In the more stimulating climates of northwestern Europe and the northern United States, for example, a person is considered sick who does not enjoy exerting himself more than he is required to do. In most of the Tropics, on the other hand, people find it very easy to procrastinate and to do as little as possible. By many writers this has been ascribed to the high average temperatures, to the general lack of stimulating changes of the weather and seasons, to diseases, or to economic conditions. The fact that mere existence in a large part of the rainy Tropics usually does not require much activity on the part of the

people—a mere living being easily obtained—certainly discourages exertion. However, the partial overcoming of inertia in advanced regions is related not only to the more stimulating climate and a greater necessity for labor so that the winter may be survived; it also is related to a more certain return for exertion. Indeed, nothing is quite so deadening to ambition as the conviction that one's efforts are likely to be in vain. The devastating tropical cyclones have rendered in vain innumerable efforts. They have helped produce lassitude, "laziness," and carelessness because from time to time they have swept away the products of labor and made the hard-working individual or family as poor in worldly goods as the laziest. This discouragement brought about by tropical cyclones needs to be overcome by wise insurance, if the stormier parts of the Tropics are to be adequately developed.

Likewise the occasional but effective stunning of ambition and consistent effort by devastating hurricanes increases the inborn tendency to fatalism. Hurricanes, while less freakish than tornadoes, nevertheless show strange partiality. The damage within a small area is commonly unevenly distributed; some houses in a village are destroyed while similar ones escape; some coconut trees are broken or uprooted while ones nearby survive; many persons are killed while others escape almost miraculously. These differences are often due to the varying strength of local gusts of wind, and to differences in the soil and run-off waters. But the causes of the differences are not apparent to most observers and the result is to increase superstitution and fatalism. Unquestionably any increase of these beliefs is unfortunate. That tropical cyclones tend powerfully to increase them in storm areas is indicated by many statements made to me. Rather intelligent whites have remarked that there was no use trying to lessen the destruction by tropical cyclones, as one put it, for, "if it is your turn you will be caught anyhow, no matter what you do." Another white man told me that he intended to sell out and leave the Tropics very soon, for he had noticed that "whenever a white man tries to become very rich in the Pacific islands, a hurricane comes along and makes him poor again."

The occasional destruction by a hurricane of most of the personal property of a village has undoubtedly played at least a small part in the development of communism, and it is interesting to note that an approach to communism is one of the most characteristic social and economic states among the natives of the Tropics. After a disastrous storm, a certain amount of gratuitous re-division of the remaining property is logical, as is likewise a considerable amount of donated labor. Where such conditions re-occur frequently, the development of a more or less permanent communism is considerably encouraged.

The discouragement caused by disastrous storms cooperates with other influences to create various undesirable conditions. Instead of a well balanced development, with diversified agriculture and manufacturing for the local market, generally only products that are especially profitable in a short time are produced. There is little thought for the future, and exploitation rather than wise utilization prevails. Also, instead of comfortable permanent dwellings, the tendency in the area often damaged by storms is to make cheap, temporary improvements. Instead of constructing good roads, the tendency is to get along with trails, for good roads as well as poor ones are eroded badly by the torrential run-offs characteristic of hurricanes. Bridges suffer correspondingly, and as a result, commonly are mere makeshifts, if bridges of any kind are present.

Severe tropical cyclones increase disease in several ways. The people are weakened by the strain—few of them eat or sleep sufficiently during the blow, which often lasts two days. Their diet suffers long afterwards, because of the injury to food plants. Many thousands have died of starvation or of diseases that in their weakened condition they were unable to withstand. Disease also increases with the mosquitoes that develop in the water holes washed by the torrents produced by excessive rainfall. Healthfulness also is affected by the size and location of the houses, both of which may, in turn, be related to storms. I was told that the greater vulnerability of large, two-storied houses than of small, squatty ones is one reason why most natives houses are small and low. Most native villages in interior Fiji are in valleys, although not on the lowest land, instead of upon the more healthful hilltops where drainage is better and where the refreshing trade wind commonly blows. I was informed that the greater danger from hurricanes upon hilltops was one reason for this distribution, other reasons being the greater availability of water and of more fertile land, and certain special advantages of being near a stream.

Another indirect effect of tropical cyclones relates to the variety of wild life. One of the notable biologic differences between the Tropics and midlatitudes is that in the Tropics there is in most places such a variety of living forms that one kind or another is ready and waiting to take advantage of any opportunity to prey upon man or upon plants and animals useful to him.

Many conditions help to produce the great variety of living forms in the Tropics. Perhaps the sudden changes produced by tropical cyclones are of importance in the development of new forms. It has been experimentally proven for several orders of animals and plants that sudden

changes in temperature, humidity, salinity, or other environmental conditions sometimes result in mutations (113, 144, 166, 185, 208).

In other words, some of the surviving eggs or seeds develop into forms distinctly different from their parents. Experimental studies appear to warrant an inference that some of the eggs already laid, or laid soon after the storm, yield mutants, for tropical cyclones produce temporary environmental changes of many sorts. For example, the temperature is often lowered greatly by the cold rain and the strong winds. The death of some scores of natives during a hurricane near latitude 8° S., in Timor, is ascribed by Braak to cold and exposure. The lower animals are less able than men to maintain their customary warmth in a hurricane. Changes in salinity are caused by the remarkable rise of sea level and the torrential floods of fresh rain water. The strong under currents developed by the waves also cause sudden changes in both temperature and mineral content of the water. For example, pearl divers along the Australian coast often notice unusual under currents of abnormally cold water for some time after a hurricane, as well as occasionally a day or two before one arrives. The hurricane swell arrives before the storm itself and before the swell is conspicuous upon the surface of the sea, currents induced by it may be felt below the surface. Such strong currents as these not only produce sudden changes in the composition, especially in the muddiness, of the water, but also changes of temperature and other environmental conditions for marine forms. Upon the land, changes in salinity occur even miles from the coast, caused by the large quantities of salt spray carried by the winds. The development of new forms by hybridization unquestionably is encouraged by the displacements caused by the wind, torrents and currents associated with tropical cyclones.

The local destruction of many of the established forms of life is favorable to the establishment of new species. Tropical cyclones undoubtedly sometimes afford a good opportunity for new forms, mutants, or distinctive hybrids, which had been appearing in considerable numbers for sometime but had been unable to establish themselves, because the parent species were so much more numerous that they crowded out, or else submerged, the mutants by hybridization. Tower (185) has described this condition in tropical Mexico, where in a certain locality a considerable number of each new generation of a certain genus of beetles were a new species. Yet the new species was unable to establish itself, because of the monopoly by the parent species.

DISPERSAL OF LIFE FROM ISLAND TO ISLAND IN THE PACIFIC

One of the mooted questions concerning the Pacific is the source of the biota now found upon the scattered islands. There are two schools of thought. One believes that the present distribution of land life can be explained only on the assumption that at some earlier time many of the now remote islands were connected into a continent. For example, Campbell (27), Bryan (26) and Scharff (155) think that the continent extended as far as the Tuamotus and Hawaii.

Most scientists familiar with Pacific problems do not ask for so much land, but assume a south-eastward extension of Asia to include the East Indies, Philippines, New Caledonia, Fiji and Samoa. Pilsbury (143) postulates certain large islands, for example, one that would include all of the Hawaiian islands and another that would unite the Cook, Austral, Society and Tuamotu islands.

On the other hand many botanists, zoologists and geologists, among them Skottsberg (165), Brown (25), Merrill (123), Jordan (103), Muir (131), Chamberlin (29), Schuchbert (156) and Gregory (71), consider the evidence for a Pacific continent, or of vast islands in it, as inconclusive and conflicting. They assume that the present or former agencies for distributing life are sufficiently efficient to have enabled the land forms to spread to the remote islands upon which they are found.

There are several features of the distribution of land forms that are difficult to explain on the basis of prevailing winds and ocean currents. One is the fact that many of the organisms of even the eastermost islands are related to Asiatic rather than to American forms. That is not true of all types of life. For example, Brown (25) has shown that a considerable number of Hawaiian forms, including many seed plants are derived from a few American ancestors, and Muir (131) shows that many birds and some insects were derived from Central American ancestors. But a large enough percentage of the forms are so Asiatic as to have led those scientists who have examined this particular type of evidence to doubt if the existing distribution can be explained on the basis of existing conditions. They have shown, for example, that a favorable wind (the prevailing trades) and current (the drift set in motion by the trades) should have given Hawaii many Californian and Mexican forms of littoral mollusca, if these agencies were effective in transporting these forms. Likewise, it is pointed out that the prevailing winds and currents throughout the Pacific Tropics are westward, and the numerous species of Asiatic descent

must have advanced eastward against the prevailing winds and currents. Yet the wind and currents are the only important agencies, aside from man, that might have transported the plants and animals in question from island to island.

HURRICANE WINDS AS DISPERSING AGENCIES

Is it not highly probable that tropical cyclones have played a part in the dispersal of life from island to island in the Pacific? Along the Equator are many violent westerly winds, completely overcoming the prevailing easterlies; within the Tropics or just beyond the Tropics many storms move eastward (p. 65). In moving eastward, the strong westerly wind on its equatorward side carries much with it, and sets up a strong drift as well. An illustration of the power and persistence of this occasional westerly wind is given by John Williams (203) who, driven by cannibals from Hervey Island, drifted in an open boat 500 miles to Tahiti with a constant westerly wind. Normally easterlies prevail in that portion of the ocean.

The power of the wind to transport light objects through the air, as for example when land birds and insects are carried out to sea in large numbers, is illustrated by many hurricanes. Indeed the presence of butterflies and birds far out at sea has often been noted in connection with hurricanes. A specific case is mentioned by Woods-Jones (206). During a severe northwesterly wind associated with a hurricane, hundreds of dragonflies were driven from Sumatra and Java to Cocos (Keeling) Islands, 700 miles distant. However, as the island possessed no suitable environment for dragonflies, the introduction was ineffectual in spite of the large numbers driven there. But if a marsh or other favorable environment for these insects should develop on the island, there is no question that within a short time some storm wind would stock it with dragonflies.

During his residence there, Woods-Jones noted an actual increase of the permanent fauna of Cocos (Keeling) Islands following the introduction of a new plant, tomatoes grown from seed. At first the tomatoes had no enemies, but before the first crop had ripened, an insect pest was brought by the same cyclonic gale that brought the dragonflies from Java and Sumatra. Although Cocos Islands are in the belt of trades, which blow with exceptional strength and persistence from Australia, almost no Australian species are found in the fauna. Woods-Jones presents this fact as an illustration of the generalization of Wallace that flying forms are rather well adjusted to the prevailing winds, in the same sense that aquatic forms living in a regular current commonly are so adjusted to it as not to be swept away. But the sudden, irregular, violent winds and currents,

associated with most tropical cyclones, take many individuals by surprise and carry them away from land.

Not only are animals with wings carried long distances by hurricane winds, but, as pointed out by Pilsbury (143), many forms attached to leaves are thus carried. Some of the many leaves stripped off by hurricanes are carried far, and to these parachutes are attached worms, larvae, eggs or small snails.

HURRICANE CURRENTS AS DISPERSING AGENCIES

The strength of the abnormal ocean currents set in motion by hurricane winds is mentioned repeatedly in the Pacific Islands Pilot. An illustration of their significance has been supplied by Judd (104). A few years ago the mangrove was introduced upon the island of Molokai, Hawaii. In spite of strong normal contrary currents seeds have been carried by abnormal currents to Oahu, and the tree is now establishing itself there, more than twenty-five miles from Molokai.

The fact that most of the lowland plants and animals of the wide stretch from Fiji and the Carolines to the Tuamotus and Hawaii are of the same or closely allied species, and that over the same area there is a progressive dropping out of species eastward, suggests strongly that life forms have been distributed from island to island by transporting agencies that are rather efficient, though not perfectly so. The fact that relatively few forms are of American origin (except remotely) suggests the inadequacy of the normal trade winds and normal currents as agencies of dispersal, in accord with Wallace's law concerning normal winds and currents. However, the relatively small part that South America has played in supplying forms to the Pacific islands doubtless is due partly to two special conditions. (1) There are few islands in the eastern part of the tropical Pacific. No islands lie between the Tuamotus and Peru, about 3,000 miles away. The Galapagos Islands, on the Equator, are almost the only islands north of that zone in similar longitudes. South of latitude 24° S. are only Rapanui (Easter Island), latitude 29° S.; Sala y Gomez, latitude 26° 30′ S., and San Felix and Juan Fernandez islands near the 80th meridian, not far from the South American coast. (2) Much of the western portion of tropical South America is almost barren of life, on account of the extreme aridity of the lowlands and the presence of the lofty Andes only a short distance from the coast. Somewhat similar conditions obtain over a wide belt in the North Pacific. There are almost no islands between Hawaii and North America, and much of the coast of Mexico is almost barren on account of aridity. On the other hand, the southeastern coast of Asia and the East Indies teem with forms adapted

to the climatic and soil conditions which obtain in most of the Pacific islands.

Advocates of great extensions of the Pacific lands call attention to the fact that wind and currents, even those associated with hurricanes, apparently are not effective in the dispersal of certain types of life, as shown by the absence from the coast of Queensland of certain forms known in New Caledonia. Both the normal trades and numerous hurricanes pass over New Caledonia and thence to Queensland, and yet the coconut is established at only a few points on the Queensland coast, and certain species of land snails abundant in New Caledonia are unknown in Queensland.

The general lack of the coconut in Queensland appears not to be due, however, to a lack of seed, for many sprouting coconuts may be seen along the shore. The severe droughts during the cooler season of each year, characteristic of this part of Australia, may be the factor preventing their widespread establishment on this coast.

The absence from Queensland of the large showy land snails (Placostylus), common on the islands to the eastward, may be due to the presence in Australia of enemies that prevent their establishment. The Australian bush-turkey feeds upon similar mollusca, and it has been suggested by Hedley (77) that possibly this bird is responsible for the absence of this island snail in Queensland.

HURRICANE FLOODS AS DISPERSING AGENCIES

The floods caused by the excessive rainfall associated with hurricanes influence the dispersal of land forms. There are numerous records of the fall of more than twenty inches in two days, and some records of more than sixty inches in three days. (See page 115.)

Under such conditions streams normally small may become great rivers, and carry to sea vast quantities of driftwood. The river banks are eroded badly, and many trees are undercut and are carried out to sea. During the excessive rains, large masses of dirt and loose rock upon steep hillsides may slip, sometimes temporarily damming valleys. If the dam breaks, the sudden rush of waters does its part to contribute natural rafts of driftwood with their load of land animals and seeds. Furthermore, the animals are not nearly so likely to be picked off a raft by seagulls or other birds during a hurricane as they are in ordinary weather. Hence, the absence of long rivers flowing into the Pacific, with the exception of the Chinese rivers, should not lead to the assumption that natural rafts of considerable size and biological dispersing possibilities are lacking in the

Pacific. Pilsbury (143) has made this erroneous assumption. He states: "The argument for distribution of animals by natural rafts has never been more convincingly stated than by W. D. Matthew in his paper 'Climate and Evolution.' Much of his argument, however, is not applicable to the Pacific islands. Here we have no large rivers to give forth natural rafts. If a single tree is washed to sea it must be very exceptional."

Tropical cyclones have also played a part in the distribution of peoples over the Pacific. Legendary accounts indicate that a number of island groups were discovered by occupants of boats that had been blown out of their course by storms. The discovery of New Zealand by Polynesians en route from Samoa to the Cook Islands is a specific illustration (12).

The great importance of man in distributing plants and animals of economic importance, and incidentally and inadvertently, of numerous smaller species concealed in the soil or bark or on leaves, has been emphasized by Mayor (121), Safford (154), Best (12) and Guppy (73).

RELATION TO GEOLOGIC CHANGES

The dispersal of life from island to island over the Pacific has been accomplished slowly. Undoubtedly during the geologic ages, there have been significant changes. For example, it is known that there was more than once a strait where the continuous Central America now is. Conceivably at such times the drift induced by the trade winds, and which is now diverted northward in the Atlantic to form the Gulf Stream, continued westward, carrying with it some of the seed plants and animals of the islands situated where Central America now is (25). Likewise any tropical cyclones that occurred of Caribbean region would have been more likely than now to sweep westward far into the Pacific, for the atmospheric pressure conditions prevailing over the land—especially mountainous land—seem to divert tropical cyclones.

Moreover it is known that Australia was formerly connected with Asia by way of the East Indies and New Caledonia. At such times, it is probable that the normal ocean currents were distinctly different from the present. That part of the warm equatorial current which finds its way westward between the islands and enters the Indian Ocean was formerly necessarily diverted by the continuous land into higher latitudes.

Another change during the geologic past is the lowering of the sea level during the accumulation of the continental glaciers of the several ice ages. Daly (44) believes that the sea level was lowered about sixty feet during the Pleistocene glacial epochs. Unquestionably there was some lowering of the sea level, but probably not nearly that much, for the glaciers probably were not nearly so thick as some have assumed (89, p. 125). How-

ever, any considerable lowering of the sea would result in an increase in the land area, sometimes connecting neighboring islands, and hence facilitating the local spread of land forms.

The recent great increases in the estimates of the duration of the geologic past has a bearing upon the dispersal of life in the Pacific. It is conceded that the effects of a single hurricane are small, and the reason why hurricanes have been largely ignored by the students of plant and animal distribution is because hurricanes were believed to occur only at long intervals. But now that the records show more than two score annually, on the average, in the Pacific, hurricanes take on a different aspect and their significance is increased by the fuller appreciation of the diverse ways in which they affect the lands, streams and currents. Hurricanes are less likely to be ignored as a factor in the dispersal of life when it is realized that the interval since the beginning of the Mesozoic Era probably is many times the twenty million to fifty million years it was thought to be a few decades ago. Indeed the evidence, derived by physical chemists from the study of the products of the disintegration of radioactive substances in igneous rocks of various geologic ages, indicates that probably more than a billion years have elapsed since life became abundant upon the earth. Hence, fortuitous happenings, such as the dispersal of living forms by hurricanes, have had a long time in which to succeed.

EFFECTS OF TROPICAL CYCLONES ON THE WEATHER OF MID-LATITUDES

DISCUSSION OF HYPOTHESES

All parts of the world have somewhat irregular changes of temperature, wind and precipitation from day to day, but in middle latitudes such changes are especially marked. The immediate causes of changes of weather are the passage of highs or anti-cyclones and lows or cyclones, the variations in the number and intensity of these cyclonic storms, the location of the paths followed and their speed of movement. There are several hypotheses concerning the influences which produce these changes in cyclonic storms. They may be stated as follows:

1. The cause of variations in the courses, intensity and velocity of mid-latitude cyclonic storms is the so-called "accidental variations" in the distribution at any time of cloud-cover, of snow-covered land, and of dry land which can be readily heated by the sun. The convection over the abnormally warm areas develops slightly lower air pressures, and since cyclones are attracted by abnormally low pressures, the next migrating cyclone which comes near is likely to be deflected into the abnormally warm area. Conversely, the cooler region tend to become places of higher pressure and to "repel" lows and "attract" highs. But during the clear weather and low humidity which are characteristic of a high, the snow or excessive moisture in the soil may disappear, and the area which was relatively cold soon becomes warmed by the sun, and soon may attract an oncoming low. Likewise, the abnormally warm area may be made relatively cold by the rain or snow brought by the cyclone it attracted. Thus there would be constant shifting in the courses of storms. Variations in velocity and intensity would be caused also, by changes in the pressure gradients and in the contrasts between adjacent regions with respect to temperature and pressure.

2. The variation in mid-latitude cyclonic storms is a result of the interaction of the storms themselves crowding one upon the other as they race eastward. They may be compared to a troup of unacquainted animals going in the same general direction along a lane, but with no well-defined purpose in mind. There would be many close approaches and not a few crossings of paths and variations in velocity. If it be imagined that new members spring into existence in the midst of the moving throng and that many of the older ones disappear, the analogy to the occurrences in the storm belts becomes still closer.

3. The counter current hypothesis assumes that cyclonic storms are eddies produced from time to time chiefly between masses of poleward and equatorward moving air, but to a lesser extent where the westerlies encounter high mountains or other barriers. If many cyclonic storms have such an origin, a considerable variation in tracks would occur as the storms move eastward in the westerly wind belt, partly by the crowding assumed in hypothesis 2, and partly by the variations in the masses of poleward air moving equatorward—the "Polar Front" of Bjerknes (17).

4. That the atmospheric circulation of high and middle latitudes is controlled by the polar and other large ice caps was suggested by Hobbs (80) and elaborated by him and by C. E. P. Brooks (27). Special attention was called to the probable effect of continental glaciers on the atmospheric circulation during the glacial period. Mawson (119), the Antarctic explorer, however, definitely suggested that many of the weather changes of the south temperate zone are produced by storms which develop along the coast of Antarctic. The Polar Front hypothesis of Bjerknes (17) makes the equatorward movement of the cold air of high latitude a dominant factor in mid-latitude weather.

5. A fifth hypothesis emphasizes the so-called "centers of action." According to it, the irregularity in storm tracks is mainly due to departures from normal of the air pressure in certain critical regions, chief of which are the vast areas of semi-permanent high pressures in subtropical latitudes over the ocean. As these expand or contract, intensify or weaken, the migrating storms to the poleward are alternately repelled and attracted. A further complication is that sometimes the departures migrate far from their place of origin. Arctowski (7), Brooks (21), and others have correlated weather changes in distant regions with abnormal conditions at certain critical stations. For example, Brooks reports that a forecast having considerable value can be made several days or even weeks in advance in respect to the weather in winter along the eastern coast of the United States and in western Europe by noting the departures from normal at Bermuda, a station in the midst of an important semi-permanent high. Likewise, the probable intensity of the rain-bearing summer monsoons of western India has been predicted with considerable success some weeks in advance for the past several years by a study of the pressure conditions far to the westward, in Palestine in particular.

6. Weather variations are related to sun-spots. For several years Clayton (35) has made short period forecasts of the weather in Buenos Aires on the basis of the daily variation in sun-spot activity as observed at the solar observatory at Colama, Chile, and with sufficient apparent success to lead the Argentine Government to relieve the Smithsonian Insti-

tution of the cost of maintaining this observatory. Evidence of relationship existing between the sun and the weather has been advanced by several other investigators, including Huntington (90) and Helland-Hansen and Nansen (78). Arctowski also is convinced that the changes in the centers of action are caused by solar changes.

7. My studies have lead to the conclusion that tropical disturbances, particularly tropical cyclones, profoundly influence the weather of mid-latitudes and I venture to propose a new hypothesis that tropcial disturbances are responsible for many of the irregular changes of weather in mid-latitudes.

The dominance of the Tropics in the general so-called planetary wind circulation has long been recognized. The intense solar heating along the Equator gives rise to the trades which are the dominant winds of the tropical half of the globe. The westerlies, the prevailing winds of most of the remaining half, are due in part to the descent in higher latitudes of part of the air which rises along the heat Equator, after it has descended in higher latitudes and has been deflected far to the east by the earth's rotation. The seasonal shifting with the sun of the belt of equatorial calms, the doldrums, and the resulting winds, causes many of the gradual changes in weather from week to week as the seasons pass, though not the irregular ones under discussion. These, however, may be partly explained by irregular variations in the amount of air rising in the doldrums, since accompanying any increase in the amount of air expending and rising along the Equator, there is a strengthening of the trades, and later of the westerlies. Related to these are changes in the pressure in the subtropical semi-permanent high pressure centers of action, with consequent alteration in the storm tracks in higher latitudes. That there are variations in the amount of air rising along the Equator seems highly probable since it is known that the sun gives out continually varying amounts of energy. Unfortunately, the existence of widespread fluctuations in the amount of air rising along the heat Equator is not yet demonstrated, though such fluctuations are very strongly suggested by the occurrence of the surges of pressure which frequently move across Australia from the Tropics poleward studied by Quayle (148), and also by marked variations often noted in the strength of the trades over extensive regions.

Another reaction to the varying amounts of energy received from the sun may be tropical cyclones. As these commonly pass from near the heat Equator to higher latitudes, they carry away vast quantities of energy, chiefly in the form of latent energy of water vapor.

Tropical cyclones have been known for centuries, and accounts of experiences in severe storms are very numerous. Yet so far as I know, no one

has given much consideration to their wider relations. Indeed, they appear not to have been suspected of having more than local and temporary meteorological importance. The chief reason why they have been so ignored is because they were thought to be rare phenomena. Instead, they are numerous and widespread, several tropical cyclonic disturbances occur each month in the year somewhere, and in the Summer and Autumn, large parts of the Tropics are profoundly affected, and also many parts of higher latitudes. Destructive tropical cyclones have occurred every month in the year in the Western North Pacific, in the Bay of Bengal, and in Australia, and in all but one or two months, in the South Indian Ocean, the South Pacific, and in the eastern North Pacific. In the West Indies, they are very rare in the first four months of the year, Mitchell (128) reporting none in the last 36 years, but Poey's long record includes examples (145). The more they are studied, the more widespread their distribution among the months is found to be in all regions. Moreover, although destructive hurricanes are rare in certain parts of the Tropics and are rare everywhere during winter and spring, less severe storms of tropical origin are not thus closely limited. Fortunately, few tropical cyclonic storms cause much destruction and although some cause gales simultaneously over an area several hundred miles across, most of them are destructive in a zone only a few score miles wide, and some only in a belt a few leagues wide. Then, too, the tracks followed differ so that any given locality may be hit disastrously only at considerable intervals, even in the stormiest regions. Furthermore, in general only the more violent storms have been considered worthy of mention. A false local pride leads some residents of storm-affected regions to be as silent as possible about even the storms that were violent enough to demolish practically all the houses in the district. Table 29 shows the average number of recorded tropical cyclones occurring yearly in certain regions.

TABLE 29. AVERAGE ANNUAL FREQUENCIES OF RECORDED TROPICAL CYCLONES

	Severe Hurricanes	Lesser Hurricanes and Cyclones	Cyclonic Disturbances
Western North Pacific, 110 to 140 E.	10	20	50
Central Pacific, 140 W. to 140 E.	2	4	....
Eastern North Pacific, East of 150 W.	2	3	....
Western South Pacific, 130 W. to 160 E.	5	10	10
Australian Region, 110 E. to 160 E.	5	8	10
South Indian Ocean	8	5	....
Arabian Sea	2	2	....
Bay of Bengal	2	6	2+
North Atlantic	3	2	2+
	39	60	74+

39
60
24
173

Most of the data upon which Table 29 is based is discussed on pages 27-65. The large figures for lesser tropical disturbances for Australia were the result of a study of the daily weather maps covering thirty years. The large figures for the western North Pacific are likewise based on a study of daily weather maps, especially those issued by the Japanese Imperial Marine Observatory in 1920 and 1921. The disturbances of obvious tropical origin have been selected from the storm tracks as platted by Okada. The weather maps show a total of more than one hundred tropical cyclones occurring yearly, on the average, in longitudes 110°-160° E. (less than one-seventh of the circumference of the globe)—certainly a surprising figure. Nearly all of those shown by Okada pass out of the Tropics into higher latitudes, usually not as destructive hurricanes, but, nevertheless, as distinct disturbances. In the light of such numbers, who can claim that tropical disturbances have only local significance? These far eastern longitudes yield a large fraction of the total given in Table 29, because only recorded storms are included in the tables and because most of the lesser disturbances escape record elsewhere.

The Indian Government publishes a daily weather map including the Bay of Bengal. Daily weather maps are made but not published for the West Indies. No other extensive area in the Tropics is mapped. More complete records may prove that except in longitudes 110°-150° E. there are more than twice as many tropical disturbances a year as are shown in Table 29. One reason for this belief is the large percentage of winds from abnormal directions in the trade wind belt shown for each five degree square on the monthly Pilot Charts issued by the United States Hydrographic office, based on wind roses prepared by the United States Weather Bureau from all available ship-logs. It will be noted that Table 29 gives annual averages. The number of storms in any area may fluctuate sharply, one year having perhaps two or three times as many as the next.

DIRECT EFFECTS

The direct effects of tropical cyclones upon the weather of mid-latitudes are partly the same as those produced within the Tropics and are partly different. Among those that are the same, are the changes in air pressure, wind direction and velocity, in cloudiness, humidity, and precipitation. For example, the tropical cyclones bring to southern Australia and to the United States the lowest pressure and the strongest winds, aside from those in tornadoes. They also cause the heaviest widespread rainfalls. Effects unlike those produced within the Tropics are the conspicuous differences in temperature and a wider zone of influence.

As a tropical cyclone advances from the Tropics into middle latitudes it produces a series of marked changes of weather. At some distance to the northwest of the center, in the Northern Hemisphere, cool northwesterly winds, clear skies and fine weather generally prevail. Nearer the storm center, cloudiness, heavy rainfall and strong gusty winds are the rule. Thus tropical cyclones that move northward some distance from the east coast of China or the United States bring to those regions fine spells of weather, but those that approach the coast or advance upon it, bring dark weather, then rain and strong winds. For example, two tropical cyclones that moved almost simultaneously from the Caribbean Sea and Gulf of Mexico northward to southern Canada and thence northeastward in October, 1923, brought to the eastern half of the United States most of the rain received in that month, and produced several consecutive rainy days.

The encircling winds of tropical cyclones produce notable changes of temperature in middle latitudes. The winds from the south, on the east side of the cyclonic center in the Northern Hemisphere, bring northward large quantities of tropical heat and moisture. Some of the most oppressive spells of hot weather in Japan are associated with tropical disturbances that pass northward to the west of those islands. Similarly in Australia, tropical disturbances that pass southward some distance inland bring oppressive, muggy weather to the eastern cities. On the opposite side of cyclonic disturbances, however, the wind is from higher latitudes and hence cool and relatively dry. In the Australian weather reports, there is mention of many tropical disturbances ending long sultry spells of weather. Similar welcome changes of weather occur frequently in the early autumn in eastern China and Japan as well as in the United States, whenever tropical cyclones pass northward at some distance from the coast.

INDIRECT EFFECTS

The indirect effects of tropical cyclones upon the weather of middle latitudes are of three main types; those due to disturbances in the normal planetary circulation, those due to disturbances in the so-called permanent "centers of action," and those due to the influence of the tropical storms themselves upon other cyclones in middle latitudes.

The normal planetary circulation is disturbed by the lowered surface temperatures produced by the active evaporation occasioned by the strong winds, by the agitation of the sea, and by the dense canopy of clouds. As evaporation requires much heat, the surface of the ocean is cooled appreciably by the hurricane winds. The cooling is increased by the fact that the canopy of clouds decreases insolation greatly. The latent energy in the resulting vapor is released at relatively high altitudes, where condensation

takes place, or is used up in moving air or water, and is largely lost so far as surface warmth in the storm area is concerned. The agitation of the sea also results in lower surface temperatures, since the water at even slight depths is decidedly cooler than the normal surface water of the Tropics and causes a mixing of the water. At the same time that the surface temperatures are reduced, the temperatures at considerable elevations in the atmosphere are increased, owing to the release of latent energy when condensation takes place.

Therefore a tropical cyclone at first accelerates the rise of air in lower latitudes, and in so doing speeds up the planetary circulation. But after the storm has passed out of low latitudes, or has died out, much less air rises in that portion of the doldrum belt than is normal. Hence, the trades and anti-trades are slowed up and far-reaching effects are produced upon the extra-tropical highs and westerlies. The abnormally cool surface water conditions produced by tropical cyclones may perhaps last for weeks or even months, and may be carried, with lessened intensity, into remote regions by general ocean currents. For example, Brooks (23) and others report significant effects upon the weather of northeastern United States and northwestern Europe of abnormally cool surface waters in the Gulf Stream and related drifts weeks or even months after such departures have been produced in the West Indies region. Recently the important effects of surface water temperatures of the Gulf of Mexico upon the winds and rainfall of Texas have been clearly pointed out by Tannehill (174). McEwen (116) has also recently discussed the conspicuous effects of changes in temperature of the ocean between California and Hawaii.

Another effect which is not local is that exerted upon "centers of action." When a hurricane passes near a semi-permanent high such as the Bermuda High, much air is drawn from it and is distributed elsewhere, or condensed as rain. Hence the intensity of the high is reduced, and its shape and position changed (60, pl. 18). The tracks of storms far away, even on its opposite side, are thereby affected. Likewise the slowing up of the normal planetary circulation, means that the amount of air rising along the doldrums is reduced, and the anti-trades weakened. In turn, the amount descending is lessened, and the belts of high pressure in latitudes 25°-35° do not receive their normal amount and are weakened. The irregular variation in the height and velocity of the anti-trades reported by Fassig (61) from Porto Rico and by Daingerfield (42) from Honolulu may be caused partly by such disturbances. The so-called "belt of high pressure" is completely severed whenever a depression migrates from the Tropics to higher latitude, and this happens nearly a hundred times a year, in a segment comprising only a seventh of the earth's tropical circumference. (See page 129.)

Cyclonic storms already moving eastward in mid-latitudes are deflected from their previous course by the newcomers, the lows often being attracted and the highs normally repelled. After the tropical disturbance reaches high latitudes, it becomes indistinguishable from other cyclonic disturbances occurring there unless characterized by greater intensity. The stronger storms, both recent arrivals from the Tropics or extra-tropical storms reinforced by newcomers as they move eastward, are able to break through barriers of high pressure which can stop or at least divert weaker storms. Many daily weather maps for the northeast Pacific show the effect of such impacts. The map for December 16, 1921, by Daingerfield (42) of the United States Weather Bureau, shows a tropical cyclone traceable on Philippine and Japanese maps from the Carolines on December 8th to east of Japan on the 12th, impinging against the great high which had prevailed for some days far south of Alaska. The pressure increased east of the storm as it advanced. The storm broke through the barrier of high pressure on the 17th and can be traced on the weather maps across the United States. A comparison of the validity of the several hypotheses proposed as explanation of the cause of irregular changes of weather in mid-latitudes (pp. 125-128) gives the following results:

The first hypotheses (accidental variation) doubtless has local value in forecasting, but it does not explain the wider variations from year to year. The second (jostling of storms) certainly has real value, but it is not at all contrary to the new hypothesis, which supplies an explanation for the source of many of the new storms. The third (the counter current hypothesis) helps explain the mechanics of the origin of some storms but by no means all. The fourth (that influences emanating from ice caps control weather) may be true locally but certainly is not true for most of the earth, since such storms never move far equatorward and few or no storms enter the tropical half of the world from higher latitudes. The hypothesis of "centers of action" certainly has great value, and, it fits in with the new hypothesis, which supplies an explanation for many of the variations produced in the centers. The solar hypotheses, likewise, are aided by the new hypothesis, provided variation in the number of tropical cyclones is related to solar changes of some kind, and this seems to be the fact in at least some large regions. It appears that the new hypothesis —that tropical disturbances and particularly tropical cyclonic storms, have an important influence on the weather of all latitudes,—is worthy of serious consideration, since it takes into account important phenomena hitherto ignored, and helps explain much not heretofore satisfactorily explained. The gathering of sufficient data to test adequately this hypothesis will require much time and cooperation.

ECONOMIC AND SOCIAL EFFECTS OF TROPICAL CYCLONES ON MID-LATITUDES

ECONOMIC RELATIONS

Tropical cyclones affect the people of mid-latitudes in various ways. The reduction in the yields of various crops in the affected areas tends to raise the prices of those products. For example, serious damage to the cane and banana fields of Fiji and of Queensland affects the supply and hence the price of sugar and bananas in New Zealand and in temperate Australia. Likewise, typhoon damage to the tobacco and hemp fields of the Philippines affects the supply and hence the price of these products in America and elsewhere.

All nations of mid-latitudes that possess territories or dependencies within the hurricane regions are influenced rather closely in various ways by these storms. Because of the occasional "hard times" in the dependencies, resulting from "a blow," the financial relation between dependency and mother country is sometimes strained. Instead of sending the large dividends expected by the far-away investors, the people of stricken areas call for assistance. The local governments not rarely desire a loan to make needed repairs in roads, bridges and harbors. Both these conditions make investors skeptical. Likewise, the homeland officials are often loath to approve the floating of a colonial loan to be used in a hurricane region because of the uncertainty as to how long the improvements to be carried out with it will withstand the storms. Citizens of both Fiji and Queensland mentioned this difficulty to me and feared that the publication of lists of hurricanes would make the situation worse for them.

DESTRUCTION IN MID-LATITUDES

Tropical cyclones that pass out from the Tropics notably influence the weather of higher latitudes. Many severe ones continue to be destructive storms after leaving the Tropics. For example, northern New Zealand has suffered rather severely from tropical hurricanes; southern Australia has likewise suffered; Adelaide, for instance, having been injured somewhat severely by a storm that swept across Australia from the north, March 7, 1910. The damage to northern China, Korea and Japan is still more severe. Indeed, probably a fourth as much damage to fishing boats and houses is caused by typhoons north of the Tropic of Cancer as within the Tropics proper. The philosophy of the people of these more northern regions is influenced by the typhoons much as is that of the people of the Tropics. The suddenness and severity of the destruc-

tion and its uncertainty tend to make the people fatalistic—a condition unfavorable to progress.

A concrete illustration of the economic importance in mid-latitudes of some tropical cyclones is afforded by the Japanese earthquake of September 1, 1923, which resulted in the loss of approximately 300,000 lives and property damage exceeding $3,000,000.00. Jaggar (98) reports that the swift spread of the fire, due largely to the typhoon winds, and the sudden shift in wind direction as the center passed a few hours after the earthquake, caused a large share of the loss of life in Yokohama and Tokyo. He estimates that the earthquakes directly caused the death of 10,000 to 12,000 people; that the fires that would have occurred in ordinary weather probably caused the death of 80,000 to 100,000 people, and that about 200,000 deaths may be attributed to the hurricane winds and their sudden change in direction, sweeping the fire back upon helpless people huddled, with their inflammable bedding, mats and clothing, in streets, small parks, and burned over areas. He estimates that perhaps half of the financial loss was due to the fire.

The typhoon coincident with the earthquake advanced slowly from the south-southeast, the center approaching the locus of the main earthquake somewhat before the quake occurred. Unfortunately it yielded no rain. As the typhoon advanced over Yokohama and Tokyo, the wind, which had attained a velocity of seventy miles an hour before the quake, increased and shifted characteristically with disastrous results to buildings and to the crowded multitudes. It is probable that hundreds if not thousands of lives would have been saved had there been a general appreciation of the way the winds change their direction as cyclones pass.

THE SAMOAN INCIDENT

The hurricane of March 16, 1889, is said to have prevented war between the United States and Germany. Six warships of these nations were in the bay at Apia, Samoa, and on the point of opening fire on each other. The Editor of the Independent (55) wrote:

> Then the storm broke. There were thirteen unlucky vessels afloat in Apia Bay when the sun rose. When it set, there were none. Twelve were sunk or grounded. One, the British warship "Calliope," had steamed out of the harbor mouth against the storm. If the battle had been fought, the loss of shipping could not have been greater. Of the crew of the American "Vandalia," forty-three were lost. Of the eighty Germans on the "Eber," only four were saved. When the news of the happenings reached Europe and America, the horror of it banished all thoughts of war.

As to the historical significance of this storm, Robert Louis Stevenson (168) states:

Thus in what seemed the very article of war, and within a single day, the sword arm of each of the two angry powers was broken; their formidable ships reduced to junk; the disciplined hundreds to a horde of castaways. The hurricane of March 16, made thus a marking epoch in world history; directly and at once it brought about the congress and treaty of Berlin; indirectly, and by a process still continuing, it founded the modern navy of the United States. Coming years and other historians will declare the influence of that navy.

HURRICANES AND THE RACE PROBLEM

A question, which will sometime be of far reaching importance to the people of mid-latitudes, concerns the type of people who inhabit the Tropics. Are the tropical lands to be filled to overflowing with people who are too poor to live decently and too slightly educated to be good citizens? The importation of Africans and the coolies from India, China and Japan into the Tropics has been carried on by whites for several reasons.

The hurricanes have supplemented other conditions in discouraging the colonization of desirable whites in sufficient numbers to furnish the required labor. Furthermore, the over-population of tropical lands by colored people has been encouraged by their white overseers who commonly are far more interested in securing cheap labor than in improving the condition of the workers. Cheap labor is conducive to large profits, and large profits are demanded by investors, partly because of the considerable hurricane risk. Over population is encouraged by the high temperatures and ease of obtaining a mere livelihood; but it is also encouraged, among the thoughtless, by the low property standard which prevails partly because hurricanes frequently make nearly all the laborers poor. The steady accumulation of small savings and also of minor improvements to the home and other equipment that have done so much to lead to a fairly high standard of living in many parts of the world is greatly discouraged in the Tropics by destructive hurricanes, as well as by other causes.

TROPICAL CYCLONES AND EARTHQUAKES

The coincidence of atmospheric disturbances and earthquakes has been noted by many seismologists. In his classical work on earthquakes, Milne (125) calls attention to the fact that the Calabria earthquake of 1783, Rhine earthquake of 1828, the Chilean earthquake of February 20, 1835, and the Japanese earthquake of February 22, 1880, occurred when the barometer was exceptionally low, usually indicating the passage of a cyclonic storm, and states that investigators of the earthquakes of Italy and Switzerland report that earthquakes chiefly occur with low pressure. He quotes Schmidt, a student of Oriental earthquakes, as noting that

earthquakes are rare with high barometer but numerous with low. Milne further reports that in Japan a conspicuous fall in the temperature, characteristic of the rear of cyclonic storms, is very common after earthquakes. That even slight external changes may determine the moment of earthquakes is reasonable because the inertia of the masses of rock of the earth's crust is so great that stresses and strains may accumulate until the equilibrium of the forces is far transcended. Hence conditions may be physically ripe for an earthquake for some days before it occurs. If, at such a time, a tropical cyclone or other disturbance affects the seismologically unstable area, it may initiate the earthquakes in somewhat the way that a slight push may sometimes start a land slide. The cyclonic strain may be likened to "the straw that broke the camel's back."

That severe tropical cyclones subject the earth's crust to an appreciable strain is evident when it is realized that a drop of barometric pressure of one inch means that a load of a million tons is removed from each square mile of land. Conversely, a rise in pressure puts the load on again (89). During the passage of some cyclones a load of nearly three million tons a square mile may be released and applied within a few hours.

Upon a coast the strain induced by a severe tropical cyclone is much greater than inland, and hence is especially likely to set off an earthquake if crustal conditions are favorable. On the adjacent sea, the pressure upon the underlying rocks is increased by the weight of water carried into the area by the waves made by the inblowing cyclonic winds. The waves and the lessened air pressure may cause the general sea level to rise several feet along the coast. Upon this elevated sea level, great waves roll toward the shore, further increasing the pressure upon the ocean floor. An increase of eight feet in the depth of the water increases the pressure on the underlying rocks more than five hundred pounds a square foot, or seven million tons a square mile. Such an increase in the height of sea level is common in severe tropical cyclones. Hence the advance of "mountainous" hurricane waves upon a coast induces a distinct strain upon the underlying rocks while the adjacent rocks, under the land, are being subjected to a lower pressure than usual, because of the low atmospheric pressure.

The coincidence of tropical cyclones and earthquakes have been mentioned by Styles (171), and Watson (202). Omori (138) and Stupart (170) have concluded that the exact time of some shocks is determined by the profound disturbances of pressure caused by a severe tropical cyclone. Omori (138) has presented calculations of the influence of the abnormal load of water piled up by typhoons, and mentioned the probability of it having effect on seismologically unstable coasts. He has also

observed that the more severe earthquakes occur after a considerable period of no earthquakes, or only very weak ones, and that in Japan abnormally dry years have fewer but more severe quakes than wet years. Both of these observations support the hypothesis that inertia sometimes permits stresses to accumulate far past equilibrium. Most wet years in Japan are years when many cyclones cross the islands.

A study of the coefficients of correlation between the tropical cyclones recorded in August, September and October, from 1880 to 1899, and the corresponding earthquakes of Milne's catalogue is +0.236 with a probable error of +0.082, the month being used as the unit (89, p. 300). This is not a large correlation, but in view of the fact that many earthquakes occur in regions like southern Europe and the equatorial regions of the East Indies where tropical cyclones are rare, and as most earthquakes even in the typhoon regions occur independently of these storms, the correlation is large enough to suggest that an appreciable number of earthquakes are set off by the pressure disturbances associated with such storms.

BENEFICIAL EFFECTS OF TROPICAL CYCLONES

It appears to be a general rule that every agency and event in nature has both favorable and unfavorable aspects. To be sure, the favorable aspects of many phenomena, such as lightning, unseasonable frosts, and tornadoes, are not so apparent as the unfavorable. Most people who have experienced a tropical cyclone see no beneficial effects; nevertheless, there are some.

RAINFALL

A large share of the rainfall of the drier parts of the Tropics and sub-tropics is caused by tropical cyclones. Australia is an example (148, 176). It is equally true for the drier leeward sides of mountainous islands in the trade wind belt. Obviously, so long as the trade wind blows steadily, there is little or no rainfall upon most of the leeward slopes. Even a weak tropical cyclone temporarily changes the wind directions, and may convert the lee slopes into windward slopes, thus giving them welcome rain. To accomplish this the storm does not need to pass over the island; by passing at some distance, it may yield rain, without doing damage.

The drier, western sides of many of the islands in the Trade Wind belt of the Pacific have several notable advantages over the wetter, eastern sides. The dryness of the air reduces the sensible temperature, for moist air feels hotter than dry air. The nights are also cooler upon the drier sides, because of a more rapid loss of heat by nocturnal radiation. For

sugar cane and certain other crops the sunshine of the drier slopes is more favorable than the cloudiness of the wetter slopes. Then, too, for reasons partly related to the lesser rainfall on many islands there is a larger amount of fertile land upon the drier than upon the wetter sides. But except under special conditions these drier sides are too dry to be very useful to man, unless tropical cyclones are frequent enough to yield them sufficient rain.

So far as yielding rain is concerned, tropical cyclones may be classified as three types.

1. Weak storms which yield rain without at the same time doing damage because of their winds. This type of storm is not ordinarily considered because discussions of tropical cyclones have been limited largely to destructive hurricanes. But, as tropical cyclones are of all degrees of intensity, and as the direction of the wind, and not its strength, is the distinctive characteristic of a cyclone, it is appropriate to include the weaker storms that do much good and almost no harm.

2. Distant hurricanes, many of which yield rain over a belt several times as wide as the belt of their destructive winds. Indeed, their development and passage of distant hurricanes create atmospheric disturbances that last for days, the irregular winds associated with them favor thunder showers in generally dry regions. Although a hurricane may do great damage to the narrow strip over which its center passes, this may be more than compensated for by the rain yielded in the wider belt. This is clearly recognized in Australia.

3. Severe storms characterized by torrential rains in their central area (p. 114). Although torrential rains usually do more harm than good, nevertheless, in some dry regions, even a "cloudburst" is welcome. For example, in northwestern Australia, localities that normally receive less than 20 inches of rainfall a year may receive that amount in a day or two during a hurricane, with the result that the reservoirs and water holes are filled, the level land along the stream is flooded—soon yielding a good hay crop—and the ground water table is raised appreciably. Indeed, it has been asserted by Australians that even the terribly destructive hurricanes of tropical Australia do much more good than harm.

CHANGES IN THE WEATHER

Tropical cyclones produce an agreeable change in the weather. This is, of course, not a function of the more intense part of the storm, but of the weaker storms, and the more distant ones often benefit a wide area by affording a welcome change of weather. Many depressive spells of hot weather are broken by the passage of cyclones. Still more frequently a

freshening of the wind reduces the sensible temperature, or the rain lays the dust. Within the regions where tropical cyclones are fairly numerous, minor changes of the weather are common, for a well-developed cyclone may affect the weather appreciably as far as 1,000 miles from its center, and for every severe cyclone there are many minor disturbances which bring about slight changes of weather.

According to Huntington and others (88), such changes of weather are important stimuli to mental and even to physical activity. Indeed, Huntington suspects that one of the great reasons for the backwardness of the Tropics and certain other parts of the world is the relative rarity of stimulating changes of the weather.

COOPERATION AND SCIENTIFIC STUDY

Destructive tropical cyclones have powerfully encouraged certain types of cooperation and scientific study. There are few happenings that quite so quickly break down the social barriers of caste, creed and race as the on-coming of a severe storm. In order to lessen the danger, cooperation is often prompt and persons who are normally more or less apathetic become alert. The warnings of the trained meteorologist, be he frocked priest, Japanese, German, or British, receive respectful attention from coolie, merchant and official. Upon a signal from the priest, Father Froc of Zikawei, or Father Algué of Manila, thousands of non-Christian coolies take action. Typhoons have helped one of the oldest civilizations in the world, but one in which science has not been encouraged nor cooperation the rule, to appreciate the value of science and of cooperation. The cooperation among navigators, due largely to tropical cyclones, may be illustrated by the following quotation from Froc (65):

> We beg to present this work to all those who, by their kind and constant cooperation, for many years now, have made possible the study of numerous storms, and chiefly to the sailors who very often in the midst of hard struggles with the elements, have found time to collect observations for the sake of those who would run the same risks after them. To establish each track on the maps, use has been made of at least 10, sometimes 20 or more reports received from stations on land and ships at sea; and we are glad to show our benevolent cooperators, while offering them our hearty thanks, that the task spontaneously undertaken by them has not been without reaching a very important and useful aim.

Throughout my field studies in the South Pacific, in Australia, the Philippines, China and Japan, as well as in the United States, I have had the whole-hearted cooperation and ready assistance of almost all persons of all classes who understood that I was making a study of tropical cyclones. I was impressed with the great extent that hurricanes encourage a certain sort of cooperation and scientific study.

The extent to which certain scientific work is encouraged by destructive

tropical cyclones may be further illustrated. The Australian Weather Bureau maintains or helps maintain, a number of stations to the east of Queensland, chiefly because of the occasional value of storm warnings. The Willis Island station was established in 1921 solely for this purpose. The carefully made meteorological records from these stations, including New Caledonia and the Norfolk Island, are valuable in many ways, and the observers are almost the only scientific men in their localities. In Fiji, Samoa, Tonga, and many other places, the making of the meteorological records during the hurricane season and their study by interested people, when they are published in the daily papers or posted at the Government building, makes up a considerable share of the scientific activities of those regions.

In the "Far East," a number of observatories have been supported perhaps chiefly because of the occasional great value of their typhoon warnings. Yet they carry on scientific work of several kinds throughout the year.

One of the best illustrations of the scientific importance of hurricanes is found in the West Indian region. It is said that the destructive Porto Rican hurricane of 1899, and the Galveston hurricane of 1900, led Congress to extend the work of the United States Weather Bureau in the West Indies, with the result that very important scientific studies are being made.

SYMPATHY

Devastating hurricanes also arouse widespread sympathy, and lead distant people to lend a helping hand. For example, tens of thousands of dollars were subscribed in America for the help of those rendered homeless and starving by the Swatow typhoon of August 2-4, 1922. Those who subscribed will henceforth be more interested in far away China, in storms, and in all scientific studies that may lead to reduction in their destructiveness to some slight degree. On the other hand, the persons aided by the relief will feel more friendly to foreigners and to Christians.

DEVELOPMENT OF THE TROPICS

The destruction brought about by tropical cyclones encourages the diversification of human activities, both on a larger scale and in widerspread developments. Because of the handicaps of the high temperature and the low standard of living of many of the natives, the full utilization of the Tropics is very difficult. In most parts of the Tropics, except some remote Pacific Islands, another type of handicap is the abundance of animal and plant pests (including disease germs). Apparently a fuller utilization can be most effectively accomplished by the governments or by large and strong companies developing several resources in widespread regions. In

other words, hurricanes tend powerfully to discourage any projects for the development of tropical resources, except such as are carefully considered, undertaken with courage, and carried out with skill and determination. If hurricanes were the only factor in discouraging the use in the Tropics of the individualistic and haphazard methods of development characteristic of temperate regions, they might not be considered beneficial. But they accomplish effectively and quickly what several other aspects of the tropical climates do only slowly: they make clear that the Tropics have their special problem and can be "conquered" only by those who recognize this clearly, and act accordingly.

One of the subtle difficulties of tropical development is the assumption that this development requires no special effort. But in fact it is neither simple nor easy. The hurricanes help make this evident; they put a premium on forethought, wise planning and skillful management. The alert and resourceful person also often finds a greater opportunity after a storm than he would have had if there had been none.

The strain and stress that ships are subjected to in tropical cyclones have encouraged greater care in construction, in loading, and in the training of navigators. These, in turn, have reduced the losses from the less severe storms of other regions, and from other causes.

EFFECTIVENESS OF TALENTED MEN

The destruction caused by hurricanes in the Tropics has encouraged capable young men, who might otherwise have led a life of little usefulness, to emigrate to more stimulating regions and regions of greater opportunity. In one of his biographical letters Alexander Hamilton, a native of the West Indies, states that his decision to go north was clinched by a disastrous hurricane. But many less conspicuous persons than Hamilton have moved from the seductive Tropics, where they might have dreamed their lives away, and numerous others have decided against going to the Tropics to reside, partly because of the great uncertainties imposed by disastrous hurricanes. The world as a whole has benefited thereby. The effective solution of the difficult problems of the Tropics probably awaits a fuller development of the more easily handled middle latitudes. The Tropics can not solve their own problems. Nor can an occasional white man from temperate regions do much except to gather information which will be useful whenever carefully planned and concerted attempts to develop the Tropics shall be undertaken. Such attempts will be made when the Tropics, in spite of their handicaps, offer greater opportunities for capital, labor and intelligence than the middle latitudes.

REDUCING DAMAGE BY TROPICAL CYCLONES

Obviously loss of property and life from severe tropical cyclones can not be entirely prevented, but it certainly can be greatly reduced. Indeed, it has already been greatly reduced, not only in the West Indies, but in the Pacific—notably shipping in the Philippine region.

The following are ways in which property losses may be reduced:

1. Buildings should be located so as to avoid hurricane waves and floods; if possible, they should be at least twenty feet above sea level or valley bottom.

2. Buildings should be constructed to withstand the wind. Well-built, reinforced concrete houses are nearly wind proof. Wooden buildings can be made strong enough to resist all but the very worst "blows." It is desirable that a portion of the dwelling be of reinforced concrete, with an independent roof, so that if the remainder of the house, and the main roof are torn away, a haven of safety will remain. Storms that are severe enough to damage seriously well-constructed and carefully located buildings, are very rare indeed, but not entirely lacking. For example, the residence and office of the superintendent of a sugar plantation in Fiji, constructed with great care and intelligence, was demolished. Another hurricane destroyed the upper half of a two-story concrete building at Nasouri, Fiji; a building, however, not of reinforced concrete, nor well built.

3. Considerable diversity of crops and other sources of food and income is desirable. Such diversity reduces greatly the severe hardship following a "blow." To be sure, the storm may knock off the coconuts, so that none can be harvested for two or three years, except those which were nearly ripe at the time of the storm; may break down the bananas so that none may be gathered for a year, and may greatly reduce the yield of sugar cane, breadfruit and mangoes. Nevertheless, with several types of crops, including root crops such as yams and plaintains, it is impossible that all will be seriously injured by a hurricane. From the standpoint of the White investor in tropical plantations, it is desirable that the company have holdings in more than one locality, as it is improbable that all parts of a scattered holding will be seriously damaged during the same year.

4. The very considerable advantage obtainable from even a day's warning of the approach of a hurricane makes very desirable the maintenance of one or more central weather bureau stations in each of the stormier regions, where the observations received by radio from ships and telegraph or telephone from secondary land stations can be plotted

on a weather map and the storm's course, speed, size and intensity determined. Warnings sent out announcing the approach of a cyclone may enable steps to be taken to effect great reduction in the damage done. For example, in the day or two of grace that is often so obtained, the livestock may be driven from the lowlands and valleys to avoid flood, buildings may be barricaded and braced; valuable personal property may be gathered into safe places, and small boats may be hauled high on shore.

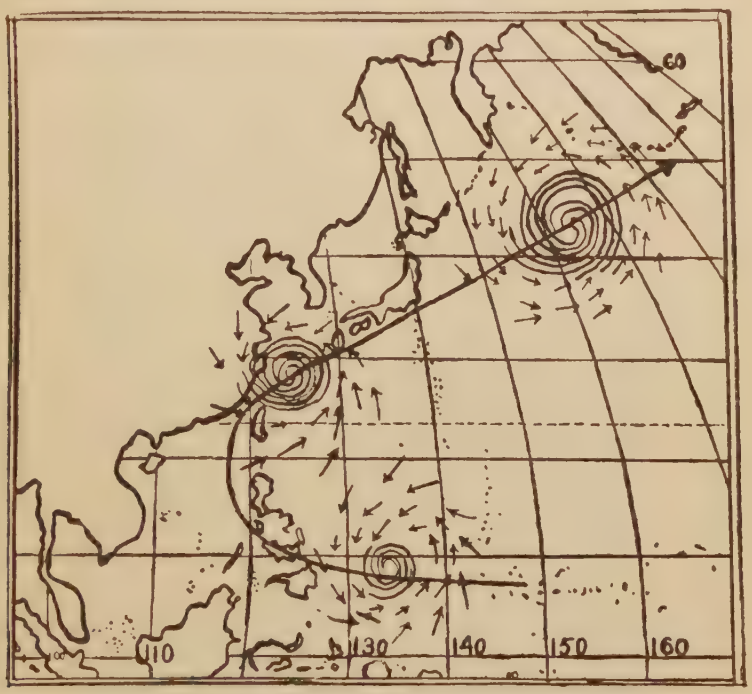


FIGURE 18.—Diagram showing path, size and direction of inwhirling winds of a typhoon at three points on a typical course along the Asiatic coast.

5. Hurricane damage to certain crops can be decreased. For example, the taller growing varieties of bananas are being supplanted in Fiji, Samoa, and in other Pacific islands by the dwarfed Chinese banana because the smaller kind is much less likely to be injured by storms. Sisal, although its coarse spine-like leaves are very strong, is badly injured by a hurricane. The injury is of a peculiar sort. Few leaves are broken, and the damage is not apparent for a day or two. After a few days the larger leaves turn black and become almost valueless for fiber. Consequently, the larger leaves should be cut during the first day or two after the storm, when they are still in excellent condition (107). Rubber trees are

subject to two kinds of hurricane damage—the loss of leaves and branches, and the more serious "bleeding" of the rubber latex or sap at every injury. Hence, a rubber plantation in a storm region should be in as protected

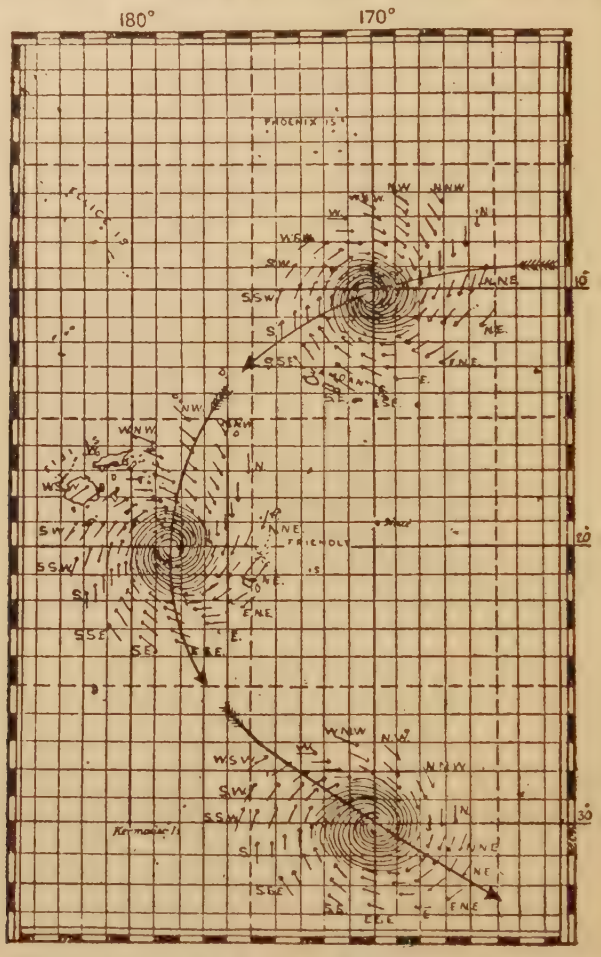


FIGURE 19.—Diagram showing path, size and direction of inwhirling winds of a hurricane at three points of a typical course in the South Pacific.

a valley as possible, and the areas planted to rubber trees should be surrounded by taller trees to afford protection from the wind.

6. The discouragement and individual poverty caused by destructive storms can be greatly reduced by insurance. Well constructed and carefully located buildings could be insured by a strong company or by the Government for a rather low premium in most parts of the tropical Pacific, for the prospects of the destruction of such buildings is rather

small in all but the stormiest areas. Crop insurance against hurricanes need not be prohibitive in expense if all the crops of a large area are insured. But since relatively few people will insure their crops unless the rate is low, and unless almost required to do so, it seems probable

FIGURE 20.—Diagram designed to assist in handling a ship in a cyclone. (From Directions to Mariners, United States Pilot for the North Pacific.)

that some sort of governmental insurance will be required in the stormier sections of the Tropics, if they are to be adequately developed. The other alternative appears to be the abandonment of much of the better land to such wealthy corporations as the United Fruit Company, which are enabled by their large sinking funds to carry their own insurance upon their many widely scattered holdings.

7. Coastal cities may be protected from hurricane waves by the construction of a sea wall, such as that erected by Galveston (p. 4).

8. Methods of reducing losses at sea have three main objectives in view: (a) To keep out of the path of approaching storms, or to keep as far as possible from the center and avoid the "dangerous semicircle" of the storm—the side upon which the cyclonic winds are strengthened by the prevailing winds of the region; (b) if involved in the storm, care should be taken to so run or drift "hove to" as to work away from instead of towards the path being followed by the storm; (c) methods of reducing the danger from the waves include guiding the ship so that the waves strike head on or stern on; using oil to reduce the waves; and, particularly if the storm's center passes over the boat, to prepare for the abrupt change in direction of wind and waves after the calm passes.

The carrying out of these objectives is greatly facilitated by an accurate knowledge of the movements, size and intensity of the storm and the location of its center. This knowledge can be gained only imperfectly by a single observer, but where scattered observers are in communication by radio, data to permit the construction of a map showing the position of the storm's center and its movements may often be quickly gathered. If several scattered ships or land stations report their meteorological observations to a well manned land station, suitable information regarding the storm can usually be promptly obtained. Near land, the danger from running aground in a storm is so great that ships unable to anchor securely usually put out to sea.

DESCRIPTIONS OF PACIFIC TROPICAL CYCLONES

A HURRICANE AT SEA IN THE SOUTH PACIFIC

FROM THE FIJI TIMES AND HERALD, SUVA, JANUARY 25, 1922, CONCERNING THE HURRICANE OF JANUARY 19-21, 1922, SOUTH OF NEW CALEDONIA.

The steamer Suva arrived in port this morning, and as she drew near the wharf many anxious eyes searched her top works to see what damage had been done in the cyclonic storm which she was reported to have encountered at the week end. But everything appeared trim and snug, until the vessel came alongside and some details were obtainable as to what had happened.

On Wednesday the captain was advised from Melbourne that a cyclonic storm was traveling south. He at once steamed full speed in the hope of getting across the track ere the storm came along.

In this he failed. On Thursday the wind started to increase in freshness, and on Friday the howling hurricane with huge seas enveloped the sturdy vessel. For 36 hours they lay to with nose to the storm and the screw doing its best to hold the vessel up to the gale. The lowest reading of the barometer was 29.32.

On Saturday the gale increased to a vicious roaring tempest. Huge seas broke over the ship. The starboard breakwater was torn off and the smoking room door was stove in and much little minor damage was done.

The passengers, and they were many, had a very anxious and rough time. Many of the passengers suffered knocks and bruises by being knocked about.

A TYPHOON IN THE CHINA SEA

WRITTEN BY PAUL R. WRIGHT, OF THE UNITED STATES ARMY TRANSPORT SHERMAN, DESCRIBING THE TYPHOON OF SEPTEMBER 1, 1919. REPRINTED IN MONTHLY WEATHER REVIEW VOL. 47, P. 660, 1919.

At daylight I crawled out again and for some hours was privileged to behold one of the wildest and most sublime scenes that men have ever looked upon and lived to tell about. The storm was at its height. The wind was coming in gusts that reached 120 miles an hour. The air was simply filled with the white spume of the sea, just as the air is filled with snow in a great storm at home. To windward it was impossible to see more than 100 feet and to leeward not much farther. Yet through this white welter we could see something of the heights and depths that hemmed us in more than masthead high, with writhing slopes like the sides of mountains.

The wind pitched itself at us with a force that made the gale of the night before seem puny and ineffective. Altogether it was an exhibition of violence unsurpassed. The nearest approach to it is afforded by Niagara Falls, as you ride up to the foot of the tumbling waters in the "Maid of the Mist," or walk under them to the "Cave of the Winds." But here both air and water were like a Niagara let loose and driving themselves down upon our little steel ship. Against the unprotected face the hard-driven spume stung like the flying particles of a sandstorm. It was terrible and magnificent. At 8 o'clock the barometer reached its lowest mark and stood at 28.58. From this point the mercury rose steadily and the wind tended to abate. The humming reverberation of the ship under the pounding seas gradually lessened and the general strain was relieved before night fell.

THE CYCLONE OF AUGUST 23, 1913

QUOTED BY HURD, TROPICAL STORMS OF THE EASTERN NORTH PACIFIC, ON REVERSE OF PILOT CHART FOR CENTRAL AMERICAN WATERS, APRIL, 1923.

On the 7th of August, 1913, the American four-masted schooner Robert Searles, Captain Sandberg, left Astoria bound for Valparaiso with a cargo of lumber. On the 23rd of the month the noon observations showed the vessel to be in latitude

17° 49′ N., longitude 121° 22′ W. At 2 o'clock of the following morning the glass began dropping and all hands started to shorten sail. The storm came on rapidly and at 6 a. m. the foresail was blown away. Other sails followed, and at 10:10 a. m. the forestay sails went by the board, leaving the vessel to go broadside to the sea. Heavy waves now swept the schooner, and shortly afterward the captain was washed overboard with the rail davits. Before 5 p. m., at which time the gale moderated, the deck load, the rudder, all sails, and the fore and main masts had disappeared.

THE CYCLONE OF SEPTEMBER 9-10, 1922

BY DAVID POLOWE AND OTHER OFFICERS OF THE S. S. BESSEMER CITY, QUOTED BY HURD ON REVERSE SIDE OF PILOT CHART FOR CENTRAL AMERICAN WATERS, APRIL, 1923.

1. The American S. S. Bessemer City, of 5,685 gross tons, 3,500 horsepower, oil-burner, full-laden with case pineapples from Honolulu, T. H., and bound for East Coast ports via the Panama Canal, on the day between the noons of September 9-10, 1922, passed through the "eye" of a cyclone in latitude 16° 12′ N., longitude 113° 44′ W.

2. Because of the severity, duration, and other points of interest of the storm the master, Captain John Murphy, and his senior watch officers decided to send in this special report.

3. The depression was discussed from all angles by all the officers, men of from five to thirty-three years of seafaring experience. Mental and written notes were made by the second officer [David Polowe] during and for five days after the storm. These notes were carefully studied, the facts studiously classified, and the suggestions advanced laboriously thought out, with conclusions arrived at as outlined below.

Excerpts from the ship's log the day before the storm, noon, September 8, to noon, September 9, 1922; position at noon, September 8, latitude 16° 58′ N., longitude 117° 07′ W.:

TIME	WIND	FORCE	BAROMETER	REMARKS
Noon	NE.	5	29.90	Moderate NE. swell.
4:00 p. m.	NE.	5	29.83	
8:00 p. m.	NNE.	6	29.84	Large NE. swell.
12:00 p. m.	N. by E.	6	29.80	Rough confused sea, heavy north swell.
4:00 a. m.	NNE.	7	29.70	Confused, long rolling north swell.
8:00 a. m.	NNE.	8	29.58	Heavy rain; heavy seas.
9:00 a. m.	NNE.	9	29.53	At 9:08 reduced speed to 70 revolutions.
10:00 a. m.	NNE.	10	29.46	At 10:40 reduced speed to 60 revolutions.
11:00 a. m.	NNE.	12	29.32	Overcast; hurricane.

The day of the storm, noon, September 9, to noon, September 10, 1922; position at noon, September 9, latitude 16° 12′ N., longitude 113° 44′ W.:

TIME	WIND	FORCE	BAROMETER	REMARKS
Noon	NNE.	12	29.15	Hurricane, mountainous seas, overcast.
1:00 p. m.	NNE.	12	28.90	Started storm oil; 1:30 to 2:35, engine full ahead but unable to handle ship.
2:00 p. m.	NNE.	12	28.28	
3:00 p. m.	NE. by E.	12	27.96	At 3 p. m. pumped fuel oil overboard.
3:30 p. m.			27.98	At 3:30 p. m. storm moderated.

TIME	WIND	FORCE	BAROMETER	REMARKS
4:00 p. m.	SW.	1	27.99	At 4 p. m. engine full ahead. Stopped use of fuel oil. Cloudy, rain, high northerly seas.
5:00 p. m.	SSE.	12	28.03	At 5 p. m. resumed use of fuel oil.
6:00 p. m.	SSE.	12	28.25	
7:00 p. m.	SSE.	12	28.46	
8:00 p. m.	SSE.	12	28.74	
9:00 p. m.	S.	12	28.84	
10:00 p. m.	S. by E.	12	28.94	Hove to with engines stopped.
11:00 p. m.	SSE.	12	29.06	Cloudy; scudding.
12:00 p. m.	SE.	10	29.16	
4:00 a. m.	SE.	10	29.24	At 4 a. m. D. R. position worked back from noon of 10th, latitude 17° 17′ N., longitude 115° 10′ W. Set 308 drift 110 k.
5:00 a. m.	SE.	8	29.28	At 4:30 a. m. engine ahead 60 revolutions. At 6:20 a. m., 65 revolutions.
8:00 a. m.	SE.	8	29.54	At 8 a. m., engine full speed ahead.
11:00 a. m.	SE.	7	29.70	

The day after the storm, noon, September 10, to noon, September 11, 1922; position at noon, September 10, latitude 16° 38′ N., longitude 114° 35′ W.:

TIME	WIND	FORCE	BAROMETER	REMARKS
Noon	SE.	7	29.70	Overcast, rain.
4:00 p. m.	SE.	5	29.72	
8:00 p. m.	SE.	4	29.82	Confused sea still running.
12:00 p. m.	SE.	4	29.85	Rough, confused sea still running.
4:00 a. m.	SE.	3	29.82	
8:00 a. m.	SE.	3	29.84	Small southerly swell.
Noon, Sept. 11	SE.	3	29.85	Small southerly swell.

The day of the storm: The excerpts of the ship's log tell the whole story. The steepness of the barometric gradient, the hurricane force of the wind, the mountainous seas (about 25 feet in height and about 500 feet from crest to crest), the fact that for more than an hour we used every bit of the 3,500 horsepower available in an unsuccessful attempt to swing the ship so as to run before the storm with the wind on the starboard quarter (Captain Murphy has never before found this ship, or any other ship, unmanageable either in typhoon, West Indian hurricane, or in extra-tropical gale)—all these factors, combined, again show the true necessity for warning mariners approaching this region of the eastern part of the North Pacific Ocean.

The extremely low pressure of 27.96 was recorded just before the ship entered the storm center. In fact, the drop was so rapid that both the third and second officers experienced an ear pressure similar to that which one experiences in an elevator which is rapidly ascending a tall building. It was a case of dI/dT, the well-known physiological formula, wherein dI equals the difference of intensity and dT the difference of time.

The center of the storm was about 18 miles in diameter. We steamed across it at a rate of about eight knots an hour. Since the storm was progressing in an opposite direction at the rate of about 10 knots an hour, we reckoned that the diameter was 18 miles, as above stated. Between 15 and 18 miles would be a conservative estimate. The difference between sail and steam again became manifest, in so much as we considered the seas within the center much less violent than those surrounding its periphery. The sky was brighter but not blue. The wind was nil.

Observation.—Captain Murphy observed several little butterflies fluttering helplessly about within the center of the storm. This would seem to suggest a wind of land origin.

DESCRIPTION OF HURRICANE AT APIA, SAMOA, MARCH 25, 1882

FROM MY CONSULATE AT SAMOA, BY WILLIAM CHURCHWARD

When morning came, a tremendous sea was rising right across the harbor. Out of nine ships which were lying snugly at anchor yesterday, the only one afloat was a small white coasting schooner of about 20 tons burden. Piled up high ,broadside on the outer westernmost reef was the Venezuela, a large barque, a most miserable wreck with her spars smashed, rigging torn to atoms, and the greater part of one side torn out of her. On the inner reef, not more than 400 yards from shore, her stern high up and bows submerged in the deep water over the edge of the reef, with only a piece of one mast standing, lay the wreck of the Solide, a big German barque. She had but lately arrived and scarcely commenced to discharge a valuable cargo, now irretrievably ruined. Inshore of her, a perfectly indistinguishable, shapeless mess of wreckage, represented all that remained of the Sheet Anchor, a large American brig, also with cargo undischarged. Going down the beach to the westward, the next thing to notice was a little American schooner blown high and dry into the German Consul's backyard, and almost 500 yards down, perfectly upright, masts sturdy, but never to go any more was a smart barque, the Brazilerra—only arrived the day before, and sunk alongside of her in embrace was a good sized schooner, the Vau-Vau, one of the German companies mosquito fleet carried to destruction by the larger ship falling athwart her when breaking away from her own anchors in the height of the hurricane. The Apia, a cutter of about 90 tons, had disappeared in toto somewhere in the deep water. In brief, the appearance of the harbor was about the most dismal sight for a marine insurance office as could well be conceived.

HURRICANES IN THE SOUTH SEAS

FROM THE ISLANDS OF THE MID-PACIFIC BY ALFRED GOLDSBOROUGH MAYER: SCIENTIFIC MONTHLY, VOL. II, PP. 142-148, 1916

Only half conscious of the present, wantonly forgetful of the past and heedless of the future, life in the South Seas passes as a day-dream, a reverie aimless as the airs that trifle among the palm leaves, only to lapse into the nothingness of things that were. Yet nature in the tropics is a trixy jade, and at times drops her seductive, soothing ways and rushes headlong into tragedy. All other memories may lapse into forgetfulness, but the day and year of the hurricane is recalled, and the story of it passes into myth and is handed down from generation to generation.

Hurricanes come in the Autumn; in that season when the long, hot calms of the tropical Summer are about to break into the steady trade winds of the Winter months. Thus in September and October in the West Indies, and in February and March in the South Pacific, the heated air rising above the sea is believed to set up an inrush from all sides and a great whirlwind gathers, aided probably by the close proximity of the developing trade winds, and by the rotation of the earth, for the swirl is always contra-clockwise in the Northern and clockwise in the Southern Hemisphere, while the storm as a whole drifts with the currents of the upper air in the turning course to westward and then away from the Equator.

The hurricane of fiction is always preceded by an ominous brooding calm with a sky of sickly green against which palm leaves stand out like spikes of copper, but in reality the great storm is usually ushered in by gales which increase in violence until they break into a riotous tumult.

The very air becomes an entity, a thing real as the rush of water, overwhelming all in its path. A roar, unearthly in its might, rises at intervals into wild shrieks that overwhelm one's voice. The solid rain drives horizontally and buildings leak more through their sides than through their roofs. The crests of waves are blown far and away, and the sea flattens under the crushing pressure of the storm, the dark waters hidden beneath a white sheet, gray swirl scudding ghost-like over all. The wind comes, not straight, but in fearful twisting swirls, and bits of seaweed strike against lighthouse windows 160 feet above the sea. One stifles. The air, no longer a pellucid nothingness, has become an enemy against which one cannot stand; above which one cannot shout, and, in the mighty presence of which, man is an ant-like

thing, his smug assumption of mastery over nature a ridiculous pretense. There is no protection anywhere, even the strongest, highest wall serves but to create a maelstrom behind it.

The trunk of stately palms bend humbly to the onrush until they thrash upon the ground, or tearing loose fly upward into the vapor of the storm. Great trees fall, but one hears no crash; houses change in shape and crumble and there is no noise from them for all sounds of earth are as silence in the presence of the vast voice of the air.

Then, after hours that seem as years, as if all nature had fallen into war and peace could never come again, the wind unexpectedly ceases and the demon of the storm smiles down upon a blighted world. A candle flame may live in the sullen air, yet all around the horizon lies the black wall of the hurricane glistening in silver where it presses on the sea, and a confusion of huge wazes come toppling in from all directions, crashing one against the other, and the barometer sinks to its lowest level. Afar off, one hears again the dull roar, then onward it comes with sudden fury, but reversed in direction, to finish the work of destruction it had but half accomplished.

After all is over the sun—the long-forgotten sun—shines out upon a land, hideous in its ruin. The forest lies in shattered skeletons and dangling here and there are blackened rag-like things that once were leaves. The houses of the village lie shapeless, strewn among the common wreckage of the palms where the great waves let them lie, and strange rocks weighing tons have risen from the sea as monuments to the reality of nature's awakening in a region where once she seemed but to dream and soothe with gentle airs and flirt with all things real. Yet tropical nature knows no mourning and laughs at death and ruin. New life seizes covetously the lost places of the old and in a few years only the trained eye of the native can detect traces of the work of the great hurricane.

Once or twice in every generation each island is devastated by such a storm. Yet so wanton is tropic life, so heedless, listless, and resigned to things that are, that nowhere in the South Seas have the natives taken the trouble to construct hurricane-proof refuge houses into which the village might retreat in time of need.

HURRICANE IN RAROTONGA, COOK ISLANDS, DECEMBER 21-22, 1831

FROM MISSIONARY ENTERPRISES IN THE SOUTH SEA ISLANDS, BY JOHN WILLIAMS

The beautiful settlement, with its luxuriant groves, its broad pathways and neat white cottages, one mass of ruins, among which scarcely a house or tree remained standing. The poor women were moving about with their children wildly looking for a place of safety, and the men were dragging their little property from beneath the ruins of their prostrate houses. The screams of the former and the shouts of the latter, together with the roaring sea, the pelting rain, the howling wind, the falling trees, and the infuriated appearance of the atmosphere presented a spectacle the most sublime and terrible, which made us stand and tremble and adore. Shortly after my arrival, a heavy sea burst in with devastating vengeance and tore away the foundation of the chapel which fell with frightful crash. The same mighty wave rolled on in its destructive course until dashed against Mr. Buzacott's excellent dwelling, which stood on a stone foundation, and laid it prostrate, on the ground. Mr. B. and I, after endeavoring to secure a small house with ropes, conveyed to it such of our books and property as we could gather up. The rain was still descending in deluging torrents, the angry lightning was darting its fiery streams among the dense black clouds which shrouded us in their gloom, the thunder, deep and loud, rolled and pealed through the heavens, the whole island trembled to its very center as the infuriated billows burst upon its shores. The crisis had arrived: the wind shifted suddenly a few points to our west; the storm was hushed, the lowering clouds began to disperse, and the sun, as a prisoner, burst forth from his dark dungeon, smiled upon us from above. We now ventured to creep out of our hiding places and were appalled at beholding the fearful desolation. The chapels, school

houses, mission houses and nearly all the dwellings of the natives were levelled to the ground;—nearly a thousand houses in all on this small island. Our property was scattered by the wind and waves. Nearly every particle of food on the island was destroyed. Scarcely a banana or plaintain tree was left either on the plains, in the valleys or upon the mountains, hundreds of thousands of which, on the preceding day, covered and adorned the land. Thousands of stately breadfruit, together with immense chestnut and other huge trees were laid prostrate on the ground or thrown upon each other in wild confusion. Of those which remained standing, many were branchless and all leafless. No spot escaped the destruction, for the gale veered gradually, round the island and performed most effectively its devastating commission. The effects of the hurricane will of necessity be long felt, and the remembrance of it will be transmitted to posterity.

CYCLONE OF APRIL 2, 1900, IN TONGA

FROM SAVAGE ISLAND BY BASIL THOMPSON

Scarce a house was left standing; the trees were naked; the graceful palms were mere ragged broomsticks stuck aslant in the earth. The ruin was complete. The government offices were an untidy heap of lumber. The great native church laid collapsed, its mighty roof unshipped from the supporting posts but still held together by its sinnet lashings, lay careened like a stranded hull.—The people were living in the open air, crawling into cover of their ruined houses to shelter from the rain. Poor souls, they bore their misfortunes with a light heart, though the crop of orange trees, from which they got their living, were uprooted, and the cocoanuts would not recover for two years. Every boat in the island was busy bringing food from the less stricken villages, and the men were saving something from the wreck by turning the fallen cocoanuts into copra.

HURRICANE AT APIA, SAMOA, MARCH 25, 1882

FROM MY CONSULATE IN SAMOA, BY WILLIAM CHURCHWARD

Turning toward the shore the sight was by no means a pretty one. Uprooted trees lay all over the place. Roofs and verandas had been torn off or shifted. Here and there were native houses completely overturned. * * * The path of the destroyer was distinctly visible on the side of the mountain where the dense bush look black and burnt up. * * * Immense quantities of native produce such as bananas, breadfruit, cocoanuts, could not fail to have been destroyed all over the group, putting the natives to sore straits, as events like these appear so unfrequently that they do not make provision against them.

We heard afterwards that Savaii suffered worse than our island. In fact, there a clean sweep had been made of nearly everything, including many European houses.

THE 1871 HURRICANE IN FIJI

FROM "THE CLIMATE OF FIJI," BY ROBERT HOLMES

Hurricane of March 20, 1871, preceded by low barometer for two weeks, and steady fall for several days. Most of the vessels had fortunately been laid up as usual in March, but many were wrecked; houses were blown down in all directions and trees broken or rooted up; poultry were killed by the thousands and growing crops of cotton, corn, cane, etc., were laid flat; every leaf not torn off was blackened as if burnt in the fire. Where houses were blown down the three days of almost incessant downpour added to the destruction of perishable goods.

HURRICANE OF 1886, FIJI

FROM FIJI TIMES, QUOTED BY ROBERT HOLMES: QUARTERLY JOURNAL, ROYAL METEOROLOGICAL SOCIETY, 1887

The scene of desolation at Rambi was indescribable, not a standing building to be seen; the spot where the coolies live, the overseers' houses, factories, stores, etc., had been swept clean by the sea, and the whole flat was covered with uprooted trees, timber, sheets of iron, tanks, broken boats, etc., in one chaotic mess.

At Vuna Point, Taviuni: Vuna is completely wrecked; the mission house, a stone building, is down; the Vuna hotel is scattered in fragments far and wide. The sea has washed away the beach road, and the large stone wharf has been swept away. Stars came out during the calm. On one plantation twenty-five per cent of the old cocoanut palms were killed.

At Vanuaso on Ugua: The hurricane wave went inland about 700 yards and with a height as it approached shore of about 18 feet. It came like a solid wall, clearing all things before it and destroying everything within its reach. In some places the water level was raised 31 feet as shown by debris left in branches of trees. Beautiful little valleys that were fringed with cocoanut trees are now covered thick with sand. The palms are bare poles, and nothing but strips remain of the breadfruit trees.

HURRICANE IN THE TUAMOTUS

FROM PACIFIC ISLANDS PILOT, VOL. II, PP. 166-167, 1920

The hurricane of 1878 devastated Niou (Grieg) Atoll. Many of the inhabitants were washed into the sea by the surf and drowned; a few were saved by tying themselves to trees. The island is about 26 feet above sea level and well wooded. It is in latitude 16° 07′ S., longitude 146° 23′ W.

Kaukura (Aura) Island (latitude 15° 40′ S., longitude 146° 51′ W.), was also completely devastated by a hurricane of 1878, the houses destroyed, cocoanut plantations demolished and vegetation generally so completely destroyed that for some years the atoll was not visible until close upon it, with the remarkable exception that, especially on the southern side, several enormous blocks of coral, some of them thirty feet high, washed up by the sea during the hurricane, were, and remain, visible for about ten miles.

THE TYPHOON OF NOVEMBER 24-25, 1912, IN SAMAR, PHILIPPINES

FROM BULLETIN OF THE PHILIPPINE WEATHER BUREAU, PP. 392-395, NOVEMBER, 1912

On the 24th of November last a destructive typhoon broke over the locality, which has occasioned the loss of not only many houses and crops, but also of a few lives.

In Guiuan. From early morning of November 24, the weather gave signs of the existence of a typhoon, and according to the notice from the Central Observatory, it was to the east of the Visayas, moving to west or west-northwest. At 6 a. m. the barometer was at 752 millimeters with winds, which at times were equally, from northwest, north-northwest. The barometer continued to fall during the whole day, the winds remaining squally from the same directions. At 2 p. m. the barometer read 747 millimeters, at 6 p. m., 741 millimeters, and at 7 p. m., 736 millimeters. From this hour it began to fall so rapidly that at 9 p. m. it marked 710 millimeters, with constant violent winds from the northwest, north-northwest, and then the winds began to back to the west, when they acquired their maximum intensity (force 12). This state of things lasted for an hour, after which the barometer rose rapidly. It was during the hour of greatest force of the winds that the buildings and planta-

tions were destroyed, and the water rose till it reached a depth of a meter and a half in front of the municipal building, while in some of the barrios such as Alingaroc, Songan, Bobon, and the west part of Tubabao it was more than 20 feet deep.

Destruction of buildings. All the buildings of light and mixed materials have suffered considerable damage; some have been totally destroyed; the great majority remaining without roof and walls. Some 350 houses were destroyed in the town alone. The buildings of strong materials that have suffered most are the city hall, the church and convent. The warehouses and houses of the Chinese merchants and of the Compania Tabacelera scarcely suffered at all. The barrios situated to N. and NW. of the town, viz., the Island of Tubabao, Alingaroc, Songan, Bobon, and Mercedes, are hte ones that have suffered most as practically every building has been destroyed, and several lives were lost owing to the rising of the water.

Plantations. In some parts, especially in the proximity of hills, two-thirds of the cocoanut plantations were lost; in some places, however, the losses do not amount to more than a quarter.

Fatalities. Twenty persons dead, 3 disappeared, 3 wounded, and 1 bruised is the list of personal victims of the typhoon. Of the 20 dead, 18 were drowned and 2 crushed to death by the falling of houses. It is supposed that the 3 who disappeared were swept away by the rushing waters and drowned. The barrio of Alingaroc had the greatest number of victims, as 11 persons were drowned in the barrio. The lieutenant and his deputy were the greatest sufferers, as the former lost his wife and 4 children, the 2 eldest being 18 and 14 years old, respectively, while the latter lost his 4 sons. All these were drowned owing to the water reaching the roofs of their houses. In Songan, 3 children were drowned, all from the same family. In Bobon 2 children were drowned and 1 disappeared. In Buyayaon 2 children disappeared. In Tubaboa, a woman drowned and a child crushed by a falling house. In Mercedes an old man was crushed by the falling of his house. In Lopoc a child, a few days old, was drowned. The other injuries were slight.

In Salcedo. The typhoon was most severe in this town. According to the parish priest the barometer fell to less than 710 millimeters. The damage done was very considerable. Almost all the houses were destroyed, and there is not a single house that has not suffered a good deal; 80 per cent of the cocoanut plantations were destroyed. The fatalities are: In the town, 1 child drowned; in the barrio of Buabua, 8 of one family drowned; in Bagton, 3 of one family crushed by a falling house. The animals dead: 9 cows, 2 horses, and 1 carabao; many goats and pigs. The water rose 2 meters in the town in the low-lying places, and 1 meter in the higher parts. It is thought that the vortex passed by the barrios of Borac and Matarinao, for before the shifting of the wind there was a calm.

In addition to the above, practically all the churches, schools, and municipal buildings were destroyed in the southern half of the province. In Basey the damage to church and convent is 15,000 pesos. In the barrio of San Pedro, town of Santa Rita, the sea was 7 meters deep in the center of the town. A large parao was swamped by the high seas between Calbayog and Santo Nino with all lives lost as well as cargo. It was bound for Masbate. The barometer at Llorento registered 700 millimeters. In the town of Hernani there was only one house left and in Villa Real only three. The provincial steamer Mayo was driven ashore in Quinapundan Bay where it had gone for shelter. The seas washed over the top of the vessel and it was carried about 300 yards inland on top of a 30 foot tidal wave, landing it among the trees. In a number of the coast barrios the sea passed over the tops of the nipa houses, drowning many more than known.

TYPHOON OF AUGUST 26-27, 1911, IN FORMOSA

FROM THE CLIMATE, TYPHOONS AND EARTHQUAKES OF THE ISLAND OF FORMOSA (TAIWAN) TAIKOKU METEOROLOGICAL OBSERVATORY, 1914

The typhoon that visited the southernmost part of Formosa on August 26 and 27, 1911, was most violent and destructive, and the barometer at Koshun fell to 702.9 mm. On this occasion the greatest velocity recorded reached 49.2 meters per second, for at this point, the cups of the anemometer were blown away and further observations were impossible; still, the terrific force of the wind which prevailed at that time may be judged from the extent to which broken pieces of tiles penetrated wooden boards or trunks of trees, in the same manner as shrapnel discharged from a gun. It is believed that the velocity reached nearly 70 meters per second or equivalent to 156 miles per hour. During the progress of this typhoon, a velocity of 54.5 meters per second, or 122 miles per hour, was reached at Taiwan. As a result of this great storm, terrible damage was inflicted in the southern part of the island; the total loss was returned as 305 dead, 378 wounded, 190 missing, and more than 30,000 houses destroyed.

THE SWATOW TYPHOON OF AUGUST 2-3, 1922

REPORTED BY CAPTAIN G. ST. M. STOCKER—REPRINTED WITH ADDITIONS BY A. MACGOWAN IN MONTHLY WEATHER REVIEW VOLUME 50, 1922

A storm, accompanied by a tidal wave, passed over Swatow and neighborhood on the night of August 2-3, 1922, devastating a large part of the Han River delta and taking a heavy toll of life and property.

Apart from such telegraphic reports of the existence of a storm to the eastward of the Balintang Channel as came to hand, it was evident to observers on Double Island, at the entrance to the port of Swatow, as early as the evening of July 29, that a depression was moving toward the coast of China, the barometer being rather low and there being a pronounced swell on the bar.

By the morning of August 2, this swell had increased perceptibly, though there was but little wind. The sky was overcast and gloomy and the atmosphere oppressive, light showers falling occasionally.

Calms and variable light airs were experienced till noon, and then the wind came away from the northeast, force 4-6, with heavy showers. The swell on the bar became very heavy, and the sea outside turbulent.

Just after sunset the whole sky and atmosphere assumed a dark yellow hue for about half an hour, which was commented on by many.

The barometer readings noted in this report are subject to a correction of +0.15 inch, the last comparison having been made on March 4, 5, 6, 1922. The time on the barograph record is one hour slower than local standard time, i.e., 120th meridian time. The readings recorded here are those of the aneroid, not the barograph.

By 8:00 p. m. on the evening of the 2nd, the aneroid read 29.20 inches, wind N.E., force 6-8, sky Nimbus, 10.

After 8 o'clock the wind slowly backed to north, increasing in force to 10, and so continued till about 1:45 a. m. on August 3.

Shortly before 1 o'clock on the morning of August 3, it was noticed that the water was much higher than normal, and by 2 o'clock it had risen to a height of about 8 feet above normal high water.

From 11:00 p. m. to 1:00 a. m. the barometer dropped each half hour as follows: 0.13 inch, 0.15 inch, 0.35 inch, 0.45 inch. After that the drop was slower, being as follows: 0.15 inch, 0.10 inch, and by 1:45 a. m. it had reached its minimum of 27.55 inches.

After 1:45 a. m. the barometer rose rapidly, the wind veering from north to

northeast, force 3-6, and at 2:00 a. m. the barometer read 27.85 inches, the wind continuing to veer to the southward and increasing. At 2:30 a. m. the barometer read 28.10 inches, wind southeast, force 5-8, and at 3:00 a. m. it read 28.60 inches, wind south, force 12.

The wind continued from the south with hurricane force till about 4:30 a. m., the barometer rising rapidly, until by 5:00 a. m. it had reached 29.40 inches, and the wind had dropped since 4:30 to force 5-7.

People in Swatow, only 4 miles west of me, agree that they experienced a period of calm, whereas I and others here only experienced a lull, commencing at about 1:45 a. m., the time of the minimum reading of the barometer, and lasting for some three-quarters of an hour, during which time the wind veered from north to south by way of east with varying force between 3 and 8, when, settling from south, it blew by 3 a. m. with force 12. A barometer there gave a corrected reading of 27.53 inches.

Both foreign and native shipping suffered heavily. Houses that escaped being blown down were washed away by the waters which spread over the whole country side, and the loss of life was enormous. (It is estimated that at least 50,000 lives were lost, drowned and washed away in a few hours.) (Some days later, the loss was estimated at over 60,000 lives.)

Owing to the general inundation, as well as to the extremely heavy rainfall which accompanied the storm, it was several days before the country became drained off, and meanwhile the tides appeared to lose their rise and fall, the surface current flowing to seaward nearly all the time, and the general level remaining above normal.

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